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GROUND WATER MONITORING GUIDANCE

FOR SOLID WASTE FACILITIES

SEPTEMBER, 1989

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
SOLID AND HAZARDOUS WASTE PROGRAM

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1.0 INTRODUCTION

Evaluation of environmental impacts at solid waste facilities is dependent on obtaining air, soil and water quality samples that are representative of the environment. Obtaining representative ground water samples requires careful attention to monitoring well design and construction and sampling procedures. This document provides an understanding of the ground water monitoring requirements (WAC 173-304-490) as stated in the Minimum Functional Standards for Solid Waste Handling (MFS). The document is intended to be utilized by state inspectors, hydrogeologists and engineers and by local health departments, public works departments and their consultants in reviewing ground water monitoring systems, proposals, and monitoring results. It is also intended to be a reference manual for other hydrogeologists and engineers who are not cognizant of or familiar with the requirements for ground water monitoring at solid waste landfills in the State of Washington.

1.1 Performance Standard

The minimum functional standards for performance relating to ground water, WAC 173-304-460 (2)(a) states "an owner or operator of a landfill shall not contaminate the ground water underlying the landfill, beyond the point of compliance."

This document provides guidance on the acceptable location, completion and documentation of ground water monitoring wells for evaluation of solid waste disposal facility performance. Guidance on sampling and chemical testing procedures for analysis of ground water samples, reporting and statistical methods is also provided.

1.2 Problem Statement

Ground waters across the state of Washington have been contaminated by leachates generated from solid waste disposal sites. Landfills have not been constructed to the minimum functional standards for design or monitored to evaluate whether they meet the performance standards. Recent efforts to implement the ground water monitoring requirements at several operating landfills have resulted in several deficiencies including:

poorly located wells,

improperly constructed wells,

wells completed with inappropriate materials, and

wells screened at inappropriate intervals to monitor the uppermost saturated zone.

In addition, few if any of the facilities with ground water monitoring systems installed have procedures for sample collection, preservation and shipment, analytical procedures and quality assurance, chain of custody control, procedures to ensure health and safety during well installation and sampling, and statistical methods to evaluate ground water quality results.

1.3 Overview

The document is divided into five main chapters which contain discussions on the following subjects;

site characterization,

monitoring well location,

monitoring well design and construction,

ground water sampling, and

statistical methods and reporting.

Regulatory sections are referenced at the beginning of each chapter which provide the specific requirements for the subjects discussed in that chapter. Chapter 2 provides definitions of terms that may be unfamiliar.

Much of the information in this document has been previously discussed in United States Environmental Protection Agency documents initially put together for the Resource Conservation and Recovery Act Subtitle C Program. The National Water Well Association, the Illinois State Water Survey, the Wisconsin Department of Natural Resources, and the United States Geologic Survey, as well as many independent researchers have provided much additional guidance on characterization and ground water monitoring at waste sites. The technical questions that drive the characterization and installation of monitoring wells are similar for solid and hazardous waste facilities. Chapter 8 contains a bibliography of reports and documents so that the reader may also become familiar with available reference information.

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2.0 DEFINITIONS

background - quality of the environment (air, soil or water) which is unaffected by waste disposal operations.

contamination - the concentration of a substance in ground water that exceeds the maximum contamination level specified in WAC 173-304-9901, or

a statistically significant increase in the concentration of a substance in the ground water where the existing concentration of that substance exceeds the maximum contamination level specified in WAC 173-304-9901, or

a statistically significant increase above background in the concentration of a substance which;
is not specified in WAC 173-304-9901, and
is present in the solid waste, and
has been determined to present a substantial risk to human health or the environment in the concentrations found at the point of compliance.

closure/post closure care period - the period of time during which actions are taken to close the facility in conformance with applicable regulations and at least twenty years or the time period in which the site becomes stabilized (i.e., little or no settlement, gas production or leachate generation).

Ecology - Department of Ecology

downgradient - the location in the aquifer flow field that ground water flows horizontally away from the facility of interest. The gradient and flow direction in the aquifer are determined from ground water elevation data from monitoring wells.

hydrostratigraphic unit - a geologic unit within the sediment or rock materials that has unique ground water characteristics distinguishing it from geologic units above and below it.

MFS - Minimum Functional Standards for Solid Waste Handling WAC 173-304.

monitoring interval - the stratigraphic interval from which ground water level measurements or ground water quality samples will be obtained.

MSCMW - Minimum Standards for Construction and Maintenance of Wells WAC 173-160.

point of compliance - that part of ground water that lies beneath the perimeter of a solid waste facilities' active area as that active area would exist at closure of the facility.

screened interval - the open or screened section of the well through which ground water recharges the well.

upgradient - the location in the aquifer flow field that ground water flows horizontally towards the facility of interest. The gradient and flow direction in the aquifer are determined from ground water elevation data from monitoring wells.

uppermost aquifer - a "geologic formation or group of formations underlying the facility which is capable of yielding monitorable quantities of water to an approved monitoring device. Site specific hydrogeologic conditions, defined in a comprehensive hydrogeologic evaluation, will dictate what is to be considered a monitorable quantity of water" (Ecology, 1988).

WAC - Washington Administrative Code

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3.0 SITE CHARACTERIZATION

The purpose of a ground water monitoring program is to evaluate the performance of the solid waste facility in terms of impacts on the quality of ground water. The ability of a ground water monitoring program to adequately evaluate facility performance relies on the quality and quantity of hydrogeologic characterization data used in designing the system and in the implementation of the ground water sampling program. Site characterization is an important first step in designing a ground water monitoring well network.

The steps to complete characterization of a site include the review of literature and available hydrogeologic information, survey of the site, completion of field investigations, data interpretation and reporting.

3.1 Regulatory Reference Sections

The sections provided below are taken from the MFS (WAC 173-304) ground water monitoring requirements and the Minimum Standards for Construction and Maintenance of Wells (WAC 173-160).

WAC 173-304-490 (2)(a) "The ground water monitoring system must consist of at least one background or upgradient well and three downgradient wells, installed at appropriate locations and depths to yield ground water samples from the uppermost and all hydraulically connected aquifers below the active portion of the facility, that;
(i) Represent the quality of background water that has not been affected by leakage from the active area; and
(ii) Represent the quality of ground water passing the point of compliance. Additional wells may be required by the jurisdictional health department in complicated hydrogeological settings or to define the extent of contamination detected."

WAC 173-304-490 (2)(h) "The owner or operator must determine and report the ground water flow rate and direction in the uppermost aquifer at least annually."

WAC 173-304-600 (3)(b) Application contents for permits for new or expanded facilities. In addition to the requirements of (a) of this subsection, each landfill application fro a permit must contain:
(i) A geohydrological assessment of the facility that addresses:
(A) Local/regional geology and hydrology, including faults, unstable slopes and subsidence areas on site;
(B) Evaluation of bedrock and soil types and properties;
(C) Depths to ground water and/or aquifer(s);
(D) Direction and flow rate of local ground water;
(E) Direction of regional ground water;
(F) Quantity, location and construction (where available) of private and public wells within a two thousand foot radius of the site;

(G) Tabulation of all water rights for ground water and surface water wells within a two thousand foot radius of the site;
(H) Identification and description of all surface waters within a one-mile radius of the site;
(I) Background ground and surface water quality assessment, and for expanded facilities, identification of impacts of existing facilities of the applicant to date upon ground and surface waters from landfill leachate discharges;
(J) Calculation of site water balance;
(K) Conceptual design of a ground water and surface water monitoring system, including proposed installation methods for these devices and where applicable a vadose zone monitoring plan;
(L) Land use in the area, including nearby residences;
(M) Topography of the site and drainage patterns.

Minimum Standards for the Construction and Maintenance of Wells (MSCMW) WAC 173-160-050 (3) "The well record shall be made on a form provided by the Department, or a reasonable facsimile, as approved by the Department. The resource protection well record shall include the following information as a minimum: Project name, if appropriate; location of well to at least 1/4, 1/4 section or smallest legal subdivision; land surface datum; well identification number; diameter; depth; and general specifications of each well; the depth, thickness and character of each bed, stratum or formation penetrated by each well; and commercial specifications of all casing and screen ; as-built diagram; and additional information as required by the Department."

3.1.1 Intent and Purpose of Regulation

The MFS do not specifically require that hydrogeologic characterization be completed. However, in order to establish a ground water monitoring system and identify ground water flow direction so that upgradient and downgradient wells can be located, site-specific hydrostratigraphic data are necessary. Onsite and laboratory evaluation of geologic materials, aquifer properties and ground water samples is necessary to understand the basic physical and chemical conditions of the site. Site lithologic, hydrostratigraphic and soils data are necessary to evaluate the potential for the landfill to contaminate the uppermost aquifer and to assess whether current operations have resulted in leachate migration from the site.

The requirement for an annual assessment of ground water flow rate sets the need for tests to determine the hydraulic conductivity of the aquifer, since ground water flow rate is a function of both the ground water gradient and hydraulic conductivity. The test(s) necessary to evaluate the aquifer permeability are most effectively completed during the characterization phase of the project, in large open drill holes, prior to completion of monitoring wells.

3.2 Literature Review

A review of all available literature pertinent to the site should be completed prior to any field investigations. Few operating facilities have a comprehensive data base of information available on which to base any hydrogeologic or hydrostratigraphic judgements. Therefore, resources such as those in Table 3-1 should be checked for any information that can lend a better understanding of site conditions.

3.3 Hydrogeologic Conceptual Model

Data on local and regional geology, ground water, soils, climatology and plant communities should be used to construct an hydrogeologic conceptual model of the site. Simply stated, a conceptual model is your best judgement or understanding of the geologic and hydrologic conditions occurring at the site. The conceptual model may start as a fairly abstract projection of site conditions based on regional data but becomes a refined understanding as site-specific data are collected. The conceptual model should be defined based on an evaluation of facility maps, geologic and hydrostratigraphic cross-sections, water-table maps and piezometric maps, and other graphic presentations and text that describe site conditions. During the literature review phase, the conceptual model should take into account all available reference information on local and regional conditions. A reconnaissance survey may provide significant additional information with which to refine the model.

Table 3-1. Potential sources of information that should be investigated for background data on site hydrogeology.

United States Geologic Survey Offices	-	topographic maps, geologic and ground water reports
local library, university or college	-	hydrogeologic reports and maps, thesis documents
Ecology regional or headquarters office	-	hydrogeologic reports and maps of local facilities, well drilling logs and state water supply bulletins
local utility, public works office or highway department	-	hydrogeologic and engineering reports, and geologic maps
Soil Conservation Office	-	soil and regional geology descriptions, maps and aerial photographs
Department of Natural Resources	-	hydrogeologic reports, maps aerial photographs
Bureau of Mines	-	geologic reports and maps

Actual site boring data provides the most significant input to the model, either confirming projected conditions or providing the data to adjust the model as necessary. Because of the potential spatial and temporal variability in geologic, hydrologic, and soils conditions, site characterization requires a high degree of technical skill and judgement in describing, mapping, sampling, analyzing, testing, data interpretation and reporting phases.

3.4 Reconnaissance Survey

The conceptual model is the basis for beginning the field investigation phase of the project. Before any actual field work is begun on the site, a reconnaissance survey should be completed. The purpose of this survey is to gain an understanding of the physical layout of the facility and the natural and man-made conditions on and near the site. A current facility map with two foot topographic contours should be utilized during the survey. The survey should include a walk over of the entire site. The physiographic position of the site, topography, vegetation, geologic materials and soil type, surface water bodies, operation practices (for operating facilities), property boundaries, aerial extent of waste disposal, roads, buildings and other structures, water supply wells and any other pertinent information should be noted, marked on a facility map and photographed.

3.5 Site Investigation

The purpose of the site investigation is to define the site hydrogeologic characteristics and potential contaminant pathways so that well locations can be identified that monitor the uppermost aquifer (see definition, Chapter 2) and all hydraulically connected aquifers. The site characterization activity should identify the depth, thickness, geologic material type and gradation, lateral extent, and hydraulic properties of the aquifer(s) present beneath the facility. The hydrogeologic conceptual model which has been constructed from the available literature and the results of the reconnaissance survey is used as the basis for beginning the actual site investigation.

This guidance document does not serve as a compendium of available field techniques, but will focus on the data needed to complete an acceptable site characterization to support a solid waste ground water monitoring system. The reader is encouraged to review Chapter 1 of the Resource Conservation and Recovery Act Ground-Water Monitoring Technical Enforcement Guidance Document (USEPA, 1986a) for a more comprehensive coverage of the topic.

3.5.1 Site Investigation Tasks

There are three major tasks involved in conducting a site characterization.

Identify the physical and chemical characteristics of the geologic materials, soils and ground water beneath the site.

Identify the uppermost and all hydraulically connected aquifers beneath the site.

Identify potential contaminant pathways, and evaluate whether ground water contamination has occurred.

The site investigation consists of direct and indirect field methods to evaluate the hydrogeologic characteristics of the site. Direct methods include boreholes and test pits. Indirect methods include surface and downhole geophysical techniques. Indirect methods may be utilized to augment information obtained in the characterization boring program or to guide location of additional borings.

3.5.2 Direct Methods

Direct methods of site investigation are necessary to complete a hydrogeologic investigation. On site borings and test pits must be separated such that interpretation of data between locations requires a minimum of extrapolation. Graphic representations of site conditions such as lithologic and hydrostratigraphic cross-sections, piezometric surface maps, and chemical data must be reasonably correlated between boring locations. In simple hydrogeologic conditions where lithologies are uniform, and laterally continuous, fewer borings are necessary. In complex hydrogeologic conditions where lithologies are not uniform or laterally continuous, additional borings will be necessary at closer spacing.

Borings can be completed with various drilling techniques. The three methods generally used for acceptable characterization borings include hollow-stem auger, cable-tool, and air rotary techniques. Each of the three drilling methods has strong and weak points. The selection of drilling method will depend on several factors including: type of geologic materials, anticipated depth of the boring, necessary lithologic samples and potential contamination. Figure 3-1 is a decision guide for the selection of a drilling method depending on site conditions. This guide shows how the various decision criteria interact in the selection of a drilling method, and shows that under some situations several methods may be acceptable.

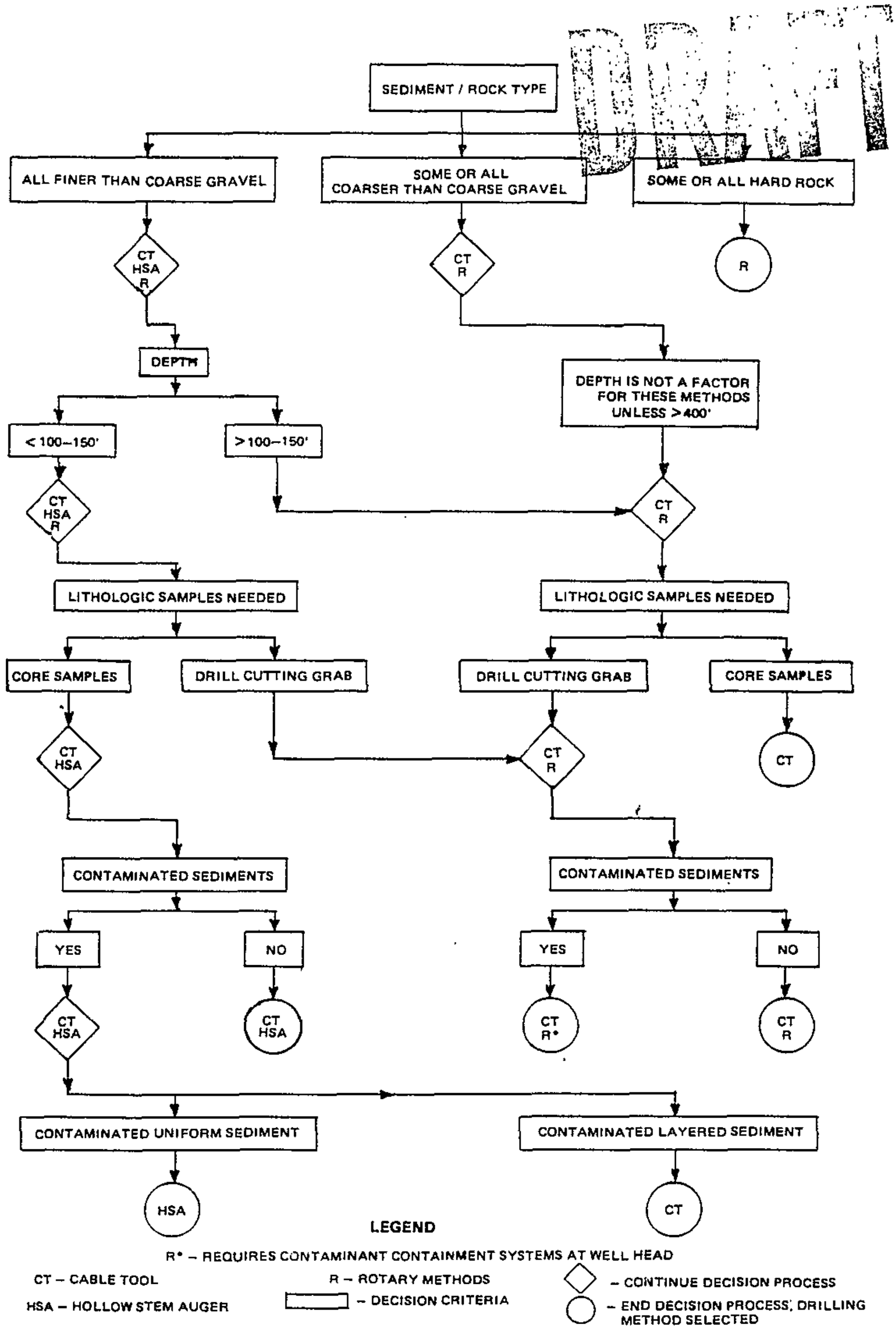

Figure 3-1. Decision Guide for Selection of Drilling Method.

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The drilling method is dependent on the site contaminant conditions. If soil contamination is expected, then a drilling method should be selected that minimizes the transfer (carry down) of contamination between lithologic units, limits contaminant spread at the ground surface. The most effective means of controlling contaminant carry down is to case off and isolate the contaminated zone at a less permeable lithologic contact, seal with grout and continue drilling in a reduced size casing. Casing reduction limits the drilling to either cable-tool or rotary methods. Drilling with air rotary methods in contaminated sediments requires the use of specialized containment systems at the well head to control release of contaminants and to minimize exposure to drilling personnel. Many different drilling tools and techniques are available for each of the various methods. The drillers experience and judicious selection and application of a drilling technique is critical to successfully identifying subsurface contamination.

The use of drilling muds and additives, such as those used in mud rotary techniques and in air rotary methods should be avoided. Additives can alter the chemical character of ground water samples and can be difficult to purge from the formation during well development. Water is the recommended additive to be utilized in drilling ground water monitoring wells or characterization borings. If water is needed to assist in the drilling program, then a sample of the water should be collected from the onsite storage tank and analyzed for the constituents in WAC 173-304-490 (2)(d).

The drilling program should include continuous or interval soil sampling (two to five foot) of the geologic materials in multiple locations on the site. Soil samples should be taken with split spoon, shelby tube, triple tube core or other minimal disturbance sampling devices. Samples of the drill cuttings between these intervals should be logged and described. After the first several borings the site specific geology should be better understood. If the stratigraphy is consistent and continuous across the site, then the sampling program can be modified to obtain drill cutting samples or undisturbed samples at every five foot interval. However, if the stratigraphy is inconsistent and complex, then additional borings with greater sampling frequency are necessary. Soil samples should also be obtained at changes in lithology.

3.5.3 Indirect Methods

Geophysical methods of various type can be used in gaining additional understanding of the site geology. The methods can be used to aid in locating borings and in correlating hydrostratigraphic units from previous boring information. The two basic geophysical types are borehole and surface methods. Borehole methods are discussed by Keys and MacCary (1981). Benson et al. (1985) provide an overview of the surface methods and applications. While use of these methods is not a necessity in characterization of solid waste sites, the data obtained can be useful in aiding with the interpretation and understanding of site boring data.

3.5.4 Characterization Data Records

A key issue in site characterization is the collection of geologic, aquifer and soils data that accurately describe site conditions. Field records of boring, sampling and testing must precisely describe the methods, materials, conditions and results. The records should be prepared by or under the direction of the project hydrogeologist or engineer (USEPA, 1986a). The data must be recorded and presented in a way that is clear and understandable. The data must include those required in WAC 173-160-050 (3) as referenced at the beginning of this chapter. At a minimum additional observations and records shall also be maintained on sample descriptions, lithologic and sample logs, sample numbers and depths, sample method and size of sampler, hammer weight and fall distance, number of blows per six inches and length of sample recovery (if appropriate to the sampling method). Records should be maintained on soil permeability sampling, laboratory testing and aquifer testing. Field logs should record weather conditions, date and time (start and finish of work on each well), horizontal coordinates to the nearest 0.5 feet, elevation to the nearest 0.01 feet of the top of monitoring well casing and the ground surface. The drilling method, equipment, drilling company and crew should be recorded as well as heave conditions and quantities, problems encountered during drilling, and any other pertinent observations.

3.5.5 Aquifer Tests

Field testing to characterize the aquifer hydraulic properties is necessary to evaluate the aquifer flow rate. Aquifer tests stress the aquifer, usually via water withdrawal. Water level responses are measured within the pumping well (single well test), or within the pumping well and observation wells (multiple well test). The field methods for conducting aquifer tests and any additional tests to characterize the physical or chemical conditions at the site should follow accepted hydrogeologic practices. Geological Survey reports (Ferris et al., 1962; Bentall et al., 1963; and Lohman, 1979) and other reference reports (Kruseman and De Ridder, 1970) and books (Driscoll, 1986; Freeze and Cherry, 1979; and Todd, 1980) are available that discuss aquifer testing and analysis procedures.

3.5.6 Laboratory Tests

Sieve analysis should be conducted to characterize the grain size distribution of soil samples. Samples representative of each geologic unit should be analyzed. Laboratory tests may be needed to characterize the permeability of samples from specific geologic units. The tests should be conducted on minimally disturbed samples. The American Society for Testing Materials has specified standard procedures for permeability and sieve tests of soil materials (ASTM, 1986).

Field monitoring for chemical parameters (pH, temperature, specific conductance) should be conducted during aquifer tests, and when purging and sampling monitoring wells. Field monitoring methods for the chemical parameters are discussed by Barcelona et al. (1985), Garske and Schock (1986), and the National Council of the Paper Industry (1982). All field monitoring for chemical parameters should be conducted following appropriate equipment calibration and quality assurance procedures. Data should be recorded in field notes or on specific forms provided for the test procedure.

3.6 Data Interpretation and Reporting

The final step in characterization of a site is the data interpretation and report preparation. The report may be in the form of a permit application for a new or expanded facility which must address the requirements of a geohydrologic assessment (see Section 3.1). Local health jurisdictions and Ecology will review the report and evaluate the scope of investigative work conducted. The report should include sections on the regional hydrogeologic and climatic conditions. The information sources and data reviewed prior to the actual site investigation should be discussed. Regional facility location maps, USGS topographic maps and general geologic cross-sections should be provided to understand the regional geology.

The site specific section of the report should provide a discussion of the facility operation plan, a plan view map with all roads, buildings, other structures, waste disposal areas, current active area, local ground water wells, and topographic features of the site. The scale of the facility map should be no greater than one inch to two hundred feet. Topographic relief across the site should be shown on a maximum five foot contour interval, with two foot intervals preferred. The facility waste type (municipal, woodwaste, demolition, inert, etc.) depth of fill and quantities disposed should be discussed.

Site hydrogeologic data should be reported starting with the geologic data and continuing with hydrostratigraphic interpretation, uppermost aquifer identification, aquifer properties, ground water gradient, flow rate and direction, and ground water quality evaluation. The report format should include geologic cross-sections, piezometric surface maps of the aquifer(s), and graphic representation of water quality results. All data records including well boring and sampling logs, aquifer test data and analysis, laboratory data, geophysical logs, etc., should be provided in the report.

4.0 MONITORING WELL LOCATION

Ground water monitoring well locations are based upon an understanding of the potential contaminant pathways and flow direction(s) in the uppermost aquifer and hydraulically connected aquifers identified during the site characterization. Each facility has a unique set of hydrogeologic conditions, therefore it is not possible to write a formula for locating monitoring wells. This chapter will discuss items to consider in review of a proposed ground water monitoring system.

General industry practice is to characterize the site hydrogeology while drilling to install monitoring wells. This is done because the process of drilling wells is expensive and also requires the services of a qualified well driller and the technical direction of a professional in geology or hydrogeology. The well location is set by the location of the characterization boring. This approach often leads to wells that are poorly located. The data necessary to select well locations not only include site lithology, but also include surveyed horizontal and vertical coordinates for the wells, and may include laboratory results. These data which may not be immediately available in the field are crucial in selecting well locations and screened intervals.

4.1 Regulatory Reference Sections

The paragraphs below are taken from the MFS Ground water monitoring requirements.

WAC 173-304-490 (2)(a) "The ground water monitoring system must consist of at least one background or upgradient well and three downgradient wells, installed at appropriate locations and depths to yield ground water samples from the uppermost and all hydraulically connected aquifers below the active portion of the facility, that;
(i) Represent the quality of background water that has not been affected by leakage from the active area; and
(ii) Represent the quality of ground water passing the point of compliance. Additional wells may be required by the jurisdictional health department in complicated hydrogeological settings or to define the extent of contamination detected."

WAC 173-304-490 (2)(h) "The owner or operator must determine and report the ground water flow rate and direction in the uppermost aquifer at least annually."

4.1.1 Intent and Purpose of Regulation

The purpose of a ground water monitoring program is to evaluate the performance of the solid waste facility in terms of impacts on ground water quality. To achieve this objective, ground water samples not affected by the facility (upgradient in terms of ground water flow direction) will be compared with ground water samples that are or potentially can be affected by

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leachates from the facility (downgradient in terms of ground water flow direction). The regulation provides a statement of what is considered a minimum number of wells, one upgradient and three downgradient wells. Additional wells will be necessary for facilities that are large or that have complex hydrostratigraphic conditions.

4.2 Well Locations

Monitoring wells must be located to assess ground water quality impacts from the facility and to evaluate ground water flow direction. The wells must be located upgradient and downgradient of the facility to detect any changes in ground water quality. Wells must also be completed vertically to detect any impacts on aquifer(s) hydraulically connected with the uppermost aquifer. Surveyed horizontal and vertical coordinates for the wells and water level measurements are necessary to determine ground water flow direction. All wells in the monitoring network should be utilized to obtain ground water level data to evaluate ground water flow direction. Downgradient wells shall provide ground water quality results that can be compared with upgradient ground water quality data. The comparisons should be made using statistical methods discussed in Chapter 7. A sufficient number of downgradient wells should be installed at appropriate locations and depths to immediately detect ground water contamination at the point of compliance (see definition, Chapter 2).

4.2.1 Upgradient Well Locations

Upgradient wells must be located beyond any potential impacts from the landfill. Ground water samples from these wells should represent the quality of the water passing beneath the facility. Upgradient and downgradient wells must be screened in the same hydrostratigraphic unit so that valid evaluation of ground water flow direction and comparisons in water quality data can be made.

4.2.2 Downgradient Well Locations

Downgradient wells must be installed at the point of compliance as shown on Figure 4-1. The point of compliance is located at the downgradient limit of the permitted extent of the facility. The wells must monitor or intercept all potential contaminant pathways from the facility. Potential contaminant pathways are evaluated from the site characterization data and may include zones of higher hydraulic conductivity both laterally and vertically in the aquifer, and fracture or fault zones present in the aquifer.

4.3 The Monitoring Interval

The monitoring interval or screened interval (see definition, Chapter 2) must be placed vertically within the aquifer such that representative water quality samples and water level measurements can be obtained. Therefore, the purpose of each well must be defined. A monitoring well may be placed to monitor the water-table aquifer, the base of the aquifer, a confined or semiconfined aquifer or a specific zone within an aquifer. Each well must monitor ground water level and ground water quality, so the wells should be screened at a depth specific interval to achieve this purpose.

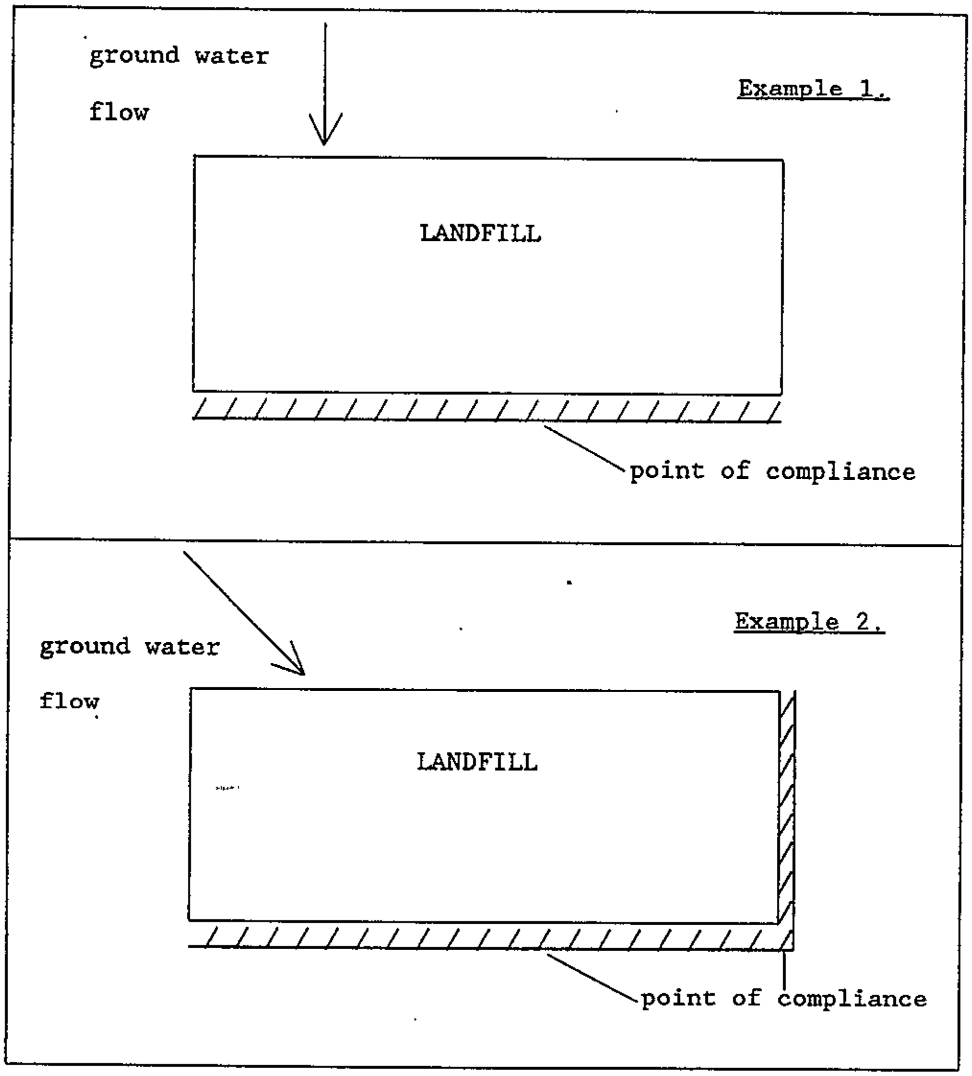

Figure 4-1. Point of Compliance for Two Example Landfills.

4.3.1 Vertical Placement and Screen Length

Screen length can vary depending on site specific conditions (Ecology, 1987). A ten foot screen length is common for ground water monitoring wells, although shorter and somewhat longer screens can be justified depending on site specific conditions. The purpose of the well, characteristics of potential contaminants and the site-specific hydrostratigraphy will dictate the length of screen.

Care should be exercised in the collection and interpretation of site characterization data and in well installation to assure that the screen is installed across a specific hydrostratigraphic unit. In horizontally layered sediments or where contamination may occur in a single zone, the screen length should be designed to monitor across a specific zone. A shorter screen may be necessary to obtain meaningful chemical results. A longer screen may allow for dilution across several saturated zones. Installation of screens across single hydrostratigraphic units is also necessary so that ground water levels accurately reflect water level head in the specific unit.

Wells intended to monitor the surface of the unconfined aquifer should be screened across the water-table. The screened length of water-table monitoring wells should have sufficient screen above the water-table to monitor seasonal or artificial fluctuations in ground water levels. The screen should be placed to assure that the interval will accommodate the full range of water-table fluctuations.

The interval to be monitored within an aquifer, or in confined or semiconfined aquifers should be identified from site boring data. The vertical extent of the unit should be identified and the length of monitoring screen should be designed accordingly. Vertical placement of the screen within the unit is dependent on the purpose of the well and the physical and chemical properties of the potential contaminants. Screened intervals for detection of a contaminant that is denser than water should be placed at the base of the unit.

4.4 Well Spacing Distance

Several methods have been utilized or proposed to evaluate an appropriate downgradient well spacing, the distance between wells. These include best professional judgement, graphical solution assuming a contaminant plume near the downgradient boundary of the facility, and various numerical models utilizing site characterization data. An acceptable method should provide monitoring wells at locations that account for site hydrogeologic conditions.

To date, most hydrogeologic investigations have relied on best professional judgement for determining the distance separating downgradient wells. This judgement is based on a thorough evaluation and understanding of hydrogeologic characterization data, knowledge of saturated and unsaturated flow paths, and environmental fate and transport characteristics of the potential contaminant(s). Table 4-1 lists factors that should be considered in evaluating the distance between wells.

Table 4-1. Factors that influence the distance between individual monitoring wells (modified after USEPA, 1986a).

Closer well spacing if the site:	Wider well spacing if the site:
is very small	
has fill materials near the landfill (where preferential flow may occur)	
has complicated geology - closely spaced fractures - faults - tight folds - discontinuous structures	has simple geology - no fractures - no faults - no folds - continuous structures
has heterogeneous conditions - variable hydraulic conductivity - variable lithology	has homogeneous conditions - uniform hydraulic conductivity - uniform lithology
located near a recharge zone	
has a steep or variable hydraulic gradient	has a flat and constant hydraulic gradient
is characterized by low dispersivity	is characterized by high dispersivity
has a high seepage velocity	has a low seepage velocity

5.0 MONITORING WELL DESIGN AND CONSTRUCTION

Monitoring wells are designed and constructed to account for the specific hydrogeologic conditions encountered in the characterization borings. The primary objectives of the monitoring wells are to provide representative ground water quality samples and water level measurements. A secondary purpose may be to conduct aquifer hydraulic testing. The monitoring well must provide these uses without creating a conduit for contaminant migration to ground water.

5.1 Regulatory Reference Sections

The paragraphs below are taken from the MFS Ground water monitoring requirements.

WAC 173-304-490 (2)(a) "The ground water monitoring system must consist of at least one background or upgradient well and three downgradient wells, installed at appropriate locations and depths to yield ground water samples from the uppermost and all hydraulically connected aquifers below the active portion of the facility, that;
(i) Represent the quality of background water that has not been affected by leakage from the active area; and
(ii) Represent the quality of ground water passing the point of compliance. Additional wells may be required by the jurisdictional health department in complicated hydrogeological settings or to define the extent of contamination detected."

WAC 173-304-490 (2)(b) "All monitoring wells must be cased in a manner that maintains the integrity of the monitoring well bore hole. This casing must allow collection of representative ground water samples. Wells must be constructed in such a manner as to prevent contamination of the samples, the sampled strata, and between aquifers and water bearing strata and in accordance with chapter 173-160 WAC, Minimum standards for construction and maintain of water wells."

WAC 173-304-490 (2)(c) "The ground water monitoring program must include at a minimum, procedures and techniques for:
(i) Decontamination of drilling and sampling equipment;"

MSCMW - WAC 173-160-050 (3) "The well record shall be made on a form provided by the Department, or a reasonable facsimile, as approved by the Department. The resource protection well record shall include the following information as a minimum: Project name, if appropriate; location of well to at least 1/4, 1/4 section or smallest legal subdivision; land surface datum; well identification number; diameter; depth; and general specifications of each well; the depth, thickness and character of each bed, stratum or formation penetrated by each well; and commercial specifications of all casing and screen ; as-built diagram; and additional information as required by the Department."

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MSCMW - WAC 173-160 Part One--General Requirements and Part Three--Resource Protection Wells.
Please refer to the Appendix for the full text of this part. Table 5-1 contains a summation of the requirements.

5.1.1 Intent and Purpose of Regulation

The purpose of the MFS regulation is to provide for monitoring wells that achieve the objective of obtaining ground water samples and water level measurements that are representative of the aquifer. The purposes of the MSCMW well construction regulations are to assure that construction records are maintained, and that wells are constructed to minimum standards (see Table 5-1).

Table 5-1. Minimum Standards for Monitoring Well Construction from the MSCMW WAC 173-160 Parts One and Three.

1. The annular space between permanent wells and temporary outer casing or borehole wall shall be a minimum of four inches.
2. Wells shall not interconnect aquifers or saturated formations.
3. Well identification numbers shall be permanently attached to casing.
4. Well surface protective measures shall include;
   steel casing and/or protective casing with lockable cap or cover, and three metal guard posts, or
   reinforced concrete pad tied in to surface seal.
5. Well casing and screen shall be nonreactive with the subsurface environment.
6. The drill rig and equipment shall be steam cleaned before and after well construction.
7. Well casing and screen shall be steam cleaned and rinsed before installation, and stored off the ground on secure clean racks.
8. Filter pack shall not interfere with constituents of interest.
9. Well screens shall be commercially fabricated.
10. Casing joints shall not be glued.
11. Wells shall be developed to produce as close to turbid free samples as possible.
12. The annular space from the monitoring interval to ground surface shall be grouted with bentonite or cement-bentonite sealant. Sealants shall be installed with a tremie tube from the bottom up. The bentonite or cement-bentonite sealant must have a mud weight in the range of eleven to thirteen pounds per gallon. A concrete surface seal shall be installed to below the frost zone.
13. A minimum of two feet of bentonite seal be placed on the top of the sand pack.

5.2 Monitoring Well Design

A monitoring well is designed to achieve the monitoring and measurement objectives previously discussed. The well must be durable enough to provide a monitoring location for the life of the facility and the closure/post closure care period (see Chapter 2 for definition), able to resist chemical and physical degradation and not interfere with the quality of ground water samples. To achieve these objectives, consideration must be given to the well casing, screen, filter pack and annular sealant materials and specifications; and surface protective measures.

5.2.1 Well Casing and Screen

A variety of materials have been used in the casing and screen construction of monitoring wells at solid and hazardous waste sites. Generally these materials have included polyvinyl chloride (PVC), stainless steel (304 and 316), carbon and galvanized steel (Ecology, 1987), with a possibly few installations of polytetrafluoroethylene (PTFE, Teflon is a trademark brand of PTFE) and fiberglass reinforced epoxy. Several of these materials have limitations for the environments in which they are chemically stable. PVC deteriorates when in contact with ketones, esters and aromatic hydrocarbons (USEPA, 1986a). Steel materials of all kinds deteriorate in corrosive conditions. In addition the steel, PVC and fiberglass materials may adsorb chemical constituents from or leach constituents to ground water samples. Therefore, the casing and screen material should be selected considering ground water quality, and potential contaminants. All well construction materials and equipment shall be steam cleaned (see Table 5-1).

PVC has been used successfully in monitoring well installations at solid waste facilities. However if the monitoring well is installed to sample for organic contaminants, PTFE or stainless steel is recommended. In corrosive environments the use of nonferrous casing and screen materials is recommended.

The depth of the monitoring well must also be considered when specifying casing and screen material. The various materials have different strength characteristics for varying manufactured pipe sizes, pipe wall thickness, and thread patterns. The selected casing material should have the strength to withstand the forces at the depth of well completion. The casing joint and wall tensile strength must be capable of carrying its own weight during installation. The well casing and screen should be flush joint threaded with o-ring seals at each casing joint to prevent leakage. Solvents or glues shall not be utilized to join casing sections. Flush joint threaded casing allows for the easiest and most effective installation of sand pack and sealant materials. Care should be taken when installing nonmetallic casing materials in cold temperatures. PVC and other carbon and glass based materials become brittle in cold weather and are very susceptible to breaking. The casing completion size should allow a minimum four inch annular space (space between the inner casing and the borehole wall or temporary outer casing, see Appendix) for the installation of sand pack and sealant materials.

5.2.2 **Monitoring Well Filter Pack and Annular Sealant**
Filter packs (sand packs) should be used when the formation materials are uniformly fine grained or where the formation sediments are highly layered. Filter pack materials are used to hold formation materials in place and to act as a filter between the well screen and the formation. The filter pack holds the fine grained fraction of the formation from entering the screened interval. The materials should be inert and nonreactive in the geochemical environment. Materials such as clean quartz or silica sand, or glass beads are generally used. Sand pack material grain size should be selected on the basis of the grain size distribution of formation materials. The concept is to match the sand pack grain distribution to that of the formation materials so that most of the formation materials are retained by the sand pack. Driscoll (1986) presents a thorough discussion of how to determine the grain size distribution for sand pack materials. The screen slot size should be selected to retain about ninety percent of the sand pack material after well development.

Annular sealants are used to seal the monitoring well casing to the formation. Well seals prevent contaminant migration from the surface or subsurface to the monitoring interval or between saturated units. A monitoring well seal must extend from the sand packed interval to the ground surface. In multiple completion wells, the seal must extend from the top of the lower piezometer filter pack to the base of the filter pack of the of the next overlying piezometer, and again from the top of the uppermost sand pack to ground surface. Sealant materials should be stable and inert in the geochemical environment and not impact the quality of ground water samples from the well. Bentonite clay and bentonite-cement mixture have been used effectively in various hydrogeologic conditions to effectively seal monitoring wells to formations. These sealants must have a weight in the range of eleven to thirteen pounds per gallon, as verified on site with a mud balance (see Table 5-1).

5.3 **Monitoring Well Construction and Development**
The monitoring well is constructed according to the specifications and with the materials identified in the design. The design should be depicted in a drawing which provides depth specifications for the placement of each material. This drawing should be used in the field by the driller to construct the well. Figures 5-1 and 5-2 present typical cross-section construction details of several monitoring wells. Note the details of the construction particularly the sump casing or tail pipe section below the screen on Figure 5-1 and the bottom or end caps on both figures. The sump section allows for some particulate accumulation in the well without fouling sampling equipment. Casing end caps prevent heave of sand pack, sealant or formation materials into the well during development or sampling.

An as-built drawing of the well must be made to record the actual construction of the well. The as-built must provide a description of each material type and quantity used, field measurements made of the depth to the bottom of the well, top of sand pack, and top of bentonite. The drilling method,

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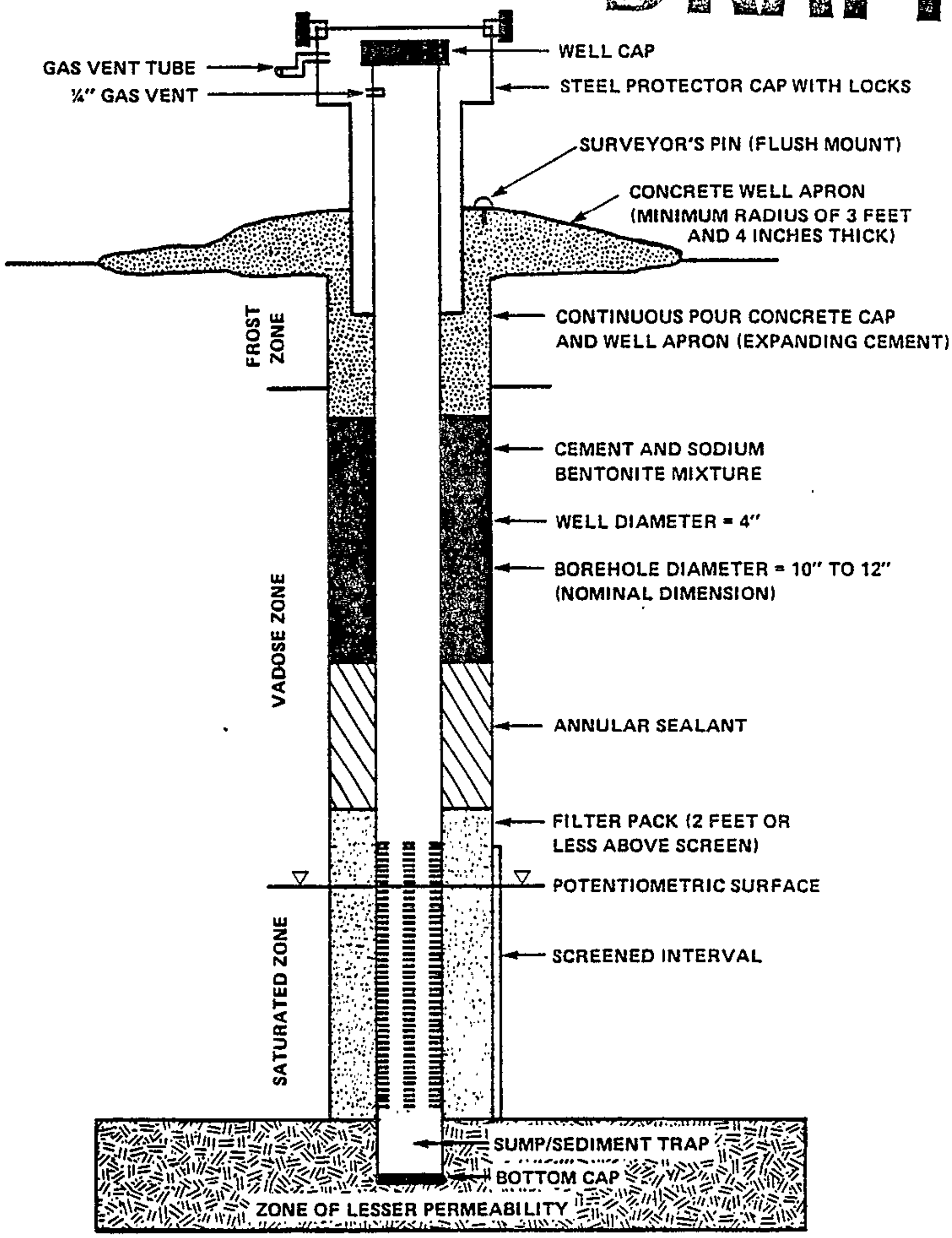

Figure 5-1. Monitoring Well Cross-Section (taken from USEPA, 1986a).

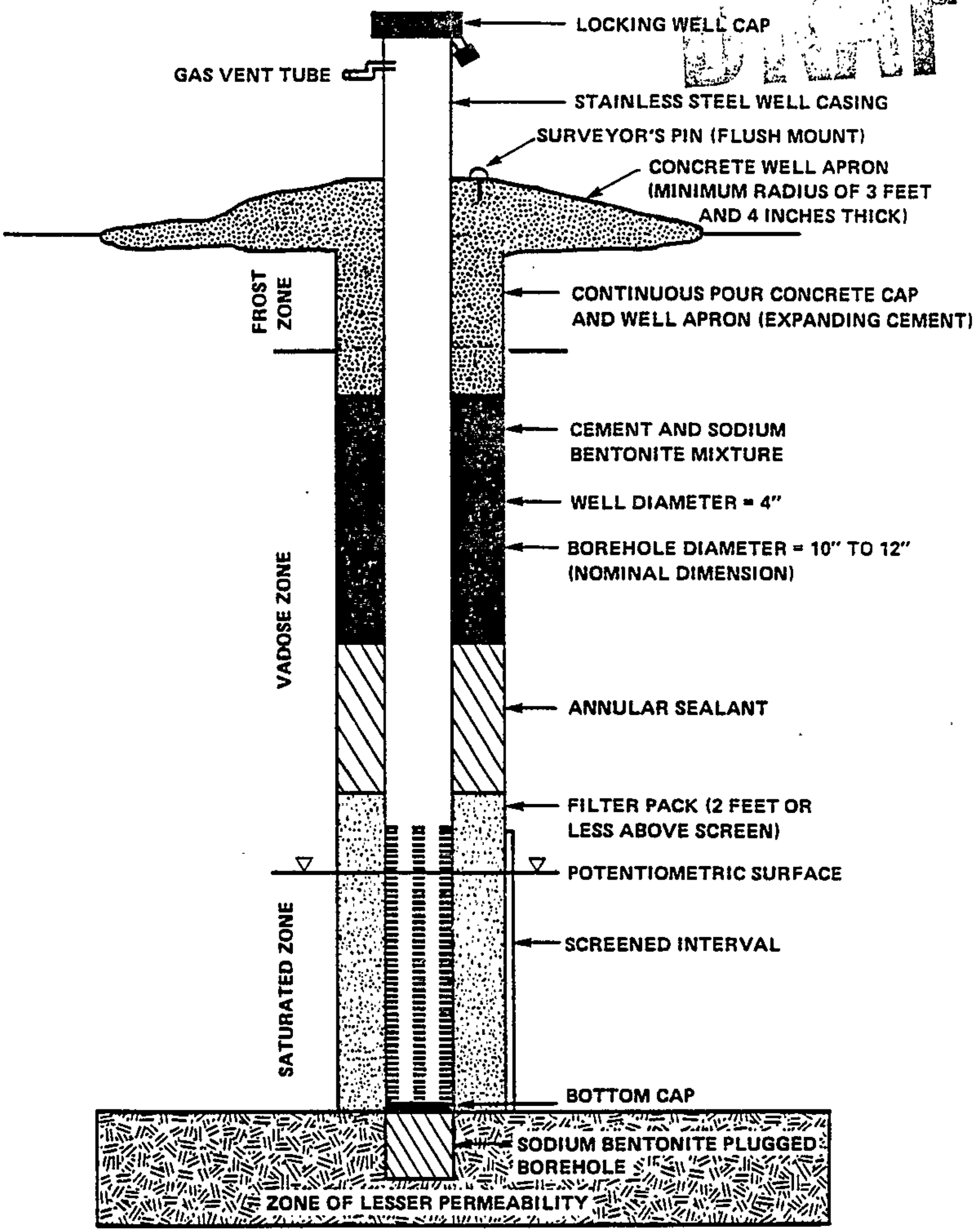

Figure 5-2. Stainless Steel Monitoring Well Cross-Section (taken from USEPA, 1986a).

filter pack grain size analysis, filter pack and sealant volumes and placement method, type of well cap and well development method must also be recorded. Figure 5-3 is an as-built drawing with appropriate well construction details recorded including the depths of all temporary casings and the well location coordinates and elevation.

Surface protection measures (see Table 5-1) should be included in all monitoring well completions. Heavy equipment (dozers, earth movers, etc.) is continually used during landfilling activities. The use of this equipment may be greater during closure of the landfill. Protective barriers, posts and markings can prevent damage to the well.

After the wells are completed they must be developed to remove clays and other fines smeared on the borehole wall from the drilling process (Scalf et al., 1981). Development restores the hydraulic continuity of the well with the aquifer. Well development should continue until turbid free water is obtained. Development procedures must not affect the quality of ground water samples. The type and duration of well development procedures should be recorded in the field notes and as-built drawings.

Various techniques are available for developing a well. The method must reverse or otherwise surge water flow back and forth through the screen and sand pack to be effective. Formation water should be used during well development. In low production aquifers an outside source of water may be necessary to begin well development. Non-formation waters should be analyzed for parameters in WAC 173-304-490 (2)(d) to evaluate the potential impact on ground water quality.

Methods for development of shallow wells include surge blocks and bailers. Some new technologies are also available which combine the surging characteristics of the surge block method and a mechanical lift pumping capability. Which ever method is selected, care should be taken not to damage the well casing or screen during development, especially when equipment is being utilized within the screened interval.

Air lift development can be an effective method but should be used only under specific circumstances. The critical factor is to prevent air entrapment in the screened interval. Air lift development should only be used in deeper aquifers or confined aquifers where the airstream jet does not enter the screened interval. This technique also requires the use of inline air filters to eliminate compressor oils from the air stream.

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Well Construction Summary

Well Designation: SM-5

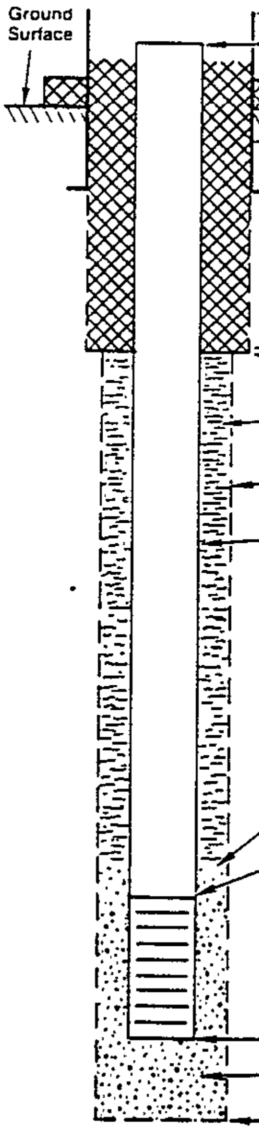
Hanford Well Number: 699-25-34B

Hanford Coordinates: N25,221.61 W33,551.98

Lambert Coordinates: N430,[illegible].424 E2,261,708.39

Date Completed: 9/5/86

All depths are from ground surface (no scale given)



Elevation of surface casing	529.65'
Elevation of reference point	529.15
Elevation of surveyor's pin	527.26'
Ground surface elevation	526.92'
Type of surface seal: Cement w/5% bentonite	
Depth of surface seal	20'
Depth of surface casing	2'
I.D. of surface casing	10"
Type of surface casing: Schedule 40 carbon steel	
Depth of original starter casing	20'
Depth of filler (seal)	20'
Type of filler: Granular bentonite	
Diameter of borehole	8"
I.D. of riser pipe	5"
Type of riser pipe: Schedule 40 carbon steel with vented locking cap	
Depth of top of sand pack	115'
Type of sand pack: Monterey crystal sand	
Depth of top of screen	118.17'
Description of screen	
Length: 20' I.D. of screen section	5"
Slot size: Unknown	
Screen construction: Type 304 stainless steel continuous slot	
Depth of bottom of screen	138.17'
Type of filler below Screen: Monterey crystal sand	
Depth of bottom of borehole	139.27'

2K8609-25.11

Figure 5-3. As-Built Construction Details for a Monitoring Well (taken from Weekes et al., 1987).

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6.0 GROUND WATER SAMPLING AND ANALYSIS

The objective of the ground water monitoring program is to obtain water quality samples that are representative of the aquifer. Therefore, the procedures and techniques utilized to obtain samples should be completely understood and thoughtfully implemented by sampling personnel.

6.1 Regulatory Reference Sections

The paragraphs below are taken from the MFS Ground water monitoring requirements.

WAC 173-304-490 (2)(c) The ground water monitoring program must include at a minimum, procedures and techniques for:

(i) Decontamination of drilling and sampling equipment;
(ii) sample collection;
(iii) sample preservation and shipment;
(iv) analytical procedures and quality assurance;
(v) chain of custody control; and
(vi) procedures to ensure employee health and safety during well installation and monitoring.
(d) Sample constituents.
(i) All facilities shall test for the following parameters:
(A) temperature;
(B) conductivity;
(C) pH;
(D) chloride;
(E) nitrate,nitrite, and ammonia as nitrogen;
(F) sulfate
(G) dissolved iron
(H) dissolved zinc and manganese;
(I) chemical oxygen demand;
(J) total organic carbon; and
(K) total coliform.
(ii) The jurisdictional health department in consultation with the department may specify additional or fewer constituents depending upon the nature of the waste; and
(iii) Test methods used to detect the parameters of (d)(i) of this subsection shall be EPA Publication Number SW-846, **Test Methods for Evaluating Solid Waste - Physical/Chemical Methods** except for total coliform which shall use the latest edition of **Standard Methods for the Examination of Water and Wastewater.**
(e) The ground water monitoring program must include a determination of the ground water surface elevation each time ground water is sampled.

WAC 173-304-490 (2)(g) The owner or operator must determine ground water quality at each monitoring well at the compliance point at least quarterly during the life of an active area (including the closure period) and the post closure care period.

6.1.1 Intent and Purpose of Regulation

The purpose of the regulations is to set forth the requirements for consistently obtaining ground water samples and water level measurements. In order to meet these requirements an owner or operator must provide written sampling procedures. The procedures should be assembled in a sampling plan. The plan should be sufficiently detailed so that an individual not familiar with the landfill could read the plan and successfully obtain the ground water samples and submit the samples to a laboratory for analysis.

6.2 Sampling Plan Procedures

The sampling plan should contain the procedures that are necessary to complete sampling of all wells in the monitoring network. The sampling plan should specify the order of sampling from least to most contaminated wells. Procedures should discuss measurement of ground water level, purging and sampling the well, quality assurance and quality control samples, chain of custody, decontamination, and laboratory methods.

The procedure should discuss the types of equipment used for depth to water measurements, purging and sampling of the wells, and field measurement of pH, temperature and specific conductance. The discussion should include equipment make and model number, equipment operation and calibration and field measurement techniques. A description of the sample container type and size for each analyte should be provided along with a sample label used to identify the sample.

Procedures should include a field sampling record sheet for each well that provides record space for field measurements and conditions as well as number and type of samples taken. An example data record sheet is provided in Figure 6-1. Table 6-1 provides a general field equipment checklist. A checklist geared to the equipment required for a specific facility can save much time when organizing for a sampling activity.

6.2.1 Ground Water Level Measurements

The sampling procedures should identify measurement of ground water level as the first activity completed prior to purging the well or obtaining ground water samples. The water level measurements are used to evaluate ground water flow direction, an evaluation that is required on an annual basis. The measurement should be repeated and recorded until two consecutive measurements are obtained within 0.01 feet (USEPA, 1986a). The measurements should be obtained from the permanently marked elevation survey point on the monitoring well casing. The methods generally used to obtain water level include steel tape and electrical tape.

The steel tape method requires the use of steel tape that is chalked over the expected interval of the depth to water. The tape is then lowered into the well and water level is noted as the wetted line on the chalk. In using a tape coated with an indicator substance, care should be taken to assure that the substance does not interfere with any sample analysis. Steel

Field Sampling Data Record

Facility Name: ______________________________ Date: __________
Location: ____

Person(s) Sampling: ____
Weather Conditions: ____
Sampling Equipment: ____
____
(water level measurement, purging, sampling, filtering, pH, specific conductance and temperature devices)

Well Number: ______________________
casing elevation(ft): _______________ depth to water: __________
water elevation(ft): _______________

Purging time: beginning ______________ ending ______________
Purge rate and volume: ____
Purge data:
time ____
pH ____
specific conductance ____
temperature ____

Sampling time: beginning ______________ ending ______________
Sample pumping rate: ____
Field parameters:
time ____
pH ____
specific conductance ____
temperature ____

Samples taken (number and type):

chloride:	________	Dissolved metals:		COD	________
nitrate:	________	zinc	________	TOC	________
nitrite:	________	iron	________	total coliform	________
ammonia:	________	manganese	________	other	________
sulfate:	________	other	________	other	________

Observations:
color (Y/N) ____
odor (Y/N) ____
turbidity (Y/N) ____
samples field filtered (Y/N) ___________________________________

Comments (discuss well condition, casing, seal, sampling problems, etc.): ______________________________
____
____
____
____

Figure 6-1. Example Field Sampling Data Record Sheet.

Table 6-1. Pre-sampling Equipment Checklist (modified after Lindorf et al., 1987).

____ 1. A map of the site that shows the access roads and the location of the wells to be sampled.

____ 2. A field notebook and Field Sampling Data Record forms for recording all observations.

____ 3. As-built drawings for all wells.

____ 4. Permanent marker for labeling samples.

____ 5. Keys for all locked wells.

____ 6. Calibrated bucket to measure purge and sample rates.

____ 7. Calculator with stopwatch to check flow rate during purging and sampling.

____ 8. Water level measuring devices and a backup that will extend deep enough to measure all wells. If using an electrical tape, bring extra batteries.

____ 9. Sampling and purging device where pumps are not dedicated to the wells.

____ 10. Camera and film.

____ 11. Extra bailer cord (if bailer will be used).

____ 12. Tubing for peristaltic pump (if peristaltic pump will be used).

____ 13. Sample containers including extras for transfer and trip blanks and to replace those that may be dropped or broken).

____ 14. Labels and chain of custody forms.

____ 15. Temperature, pH and specific conductance meters with replacements, extra batteries, standards, buffers and beakers.

____ 16. Filtering apparatus including filter membranes.

____ 17. Ice and ice chest large enough to cool and store all samples.

____ 18. A 250 ml squirt bottle to rinse off probes (bring additional reagent grade water to refill bottle and to take transfer blank samples where necessary).

____ 19. Sample equipment cleaning tubs, brushes, detergents, etc.

____ 20. Personal safety equipment including boots, surgical gloves, rain gear, hard hat, goggles and respirator if needed.

____ 21. Tools as needed: pliers, wrenches, screwdriver, scissors utility pocket knife and any replacement hardware that may be needed for well head maintenance.

____ 22. Decontamination solutions such as nitric acid, acetone, methylene chloride if needed.

tapes are subject to false indicators of depth to ground water from moisture condensing on the inside of the well casing. This can be a particular problem in the winter when temperatures drop below freezing. Also, if moisture has condensed on the casing, the tape tends to drag on the casing which can affect depth to water measurements.

An electric tape is a detector probe attached to electric lead wires that when lowered into the water, completes an electrical circuit. A voltage applied to the circuit causes a deflection on a meter, lights a light or sets off a buzzer indicating the water level. These instruments are subject to false readings and drag problems noted for steel tapes. Both measurement device types should be periodically calibrated for length of the tape, as the tapes may stretch or kink either gaining or losing length.

Other water level indicators include airlines (bubbler tubes), transducers, and water level floats. In monitoring wells where ground water quality samples are to be obtained, these instruments have limited applications because the measuring system utilizes the space in the well that is needed for the sampling device, and/or the costs of dedicating the equipment to the well is excessively high. They can be quite useful in obtaining water level data during pumping tests or in the evaluation of daily, weekly or seasonal water level fluctuations. Depending on the specifications of the system these indicators may not be capable of achieving the desired 0.01 feet precision.

6.2.2 Well Purging

To obtain a sample that is representative of aquifer conditions, the stagnant water within the monitoring well must be removed (purged). Waters entering a well from the aquifer may undergo pressure and redox potential changes. Gaseous exchange with the well atmosphere also occurs. These processes affect the chemical constituents in the water contained in the well.

In relatively high-yield aquifers, purging and sampling equipment should be located in the upper portion of the ground water in the well (Figure 6-2). In low-yield aquifers purging/sampling devices should draw down the water level in the well to near the base of the screen to assure removal of stagnant waters (Figure 6-3). In wells monitoring lower units within an aquifer or monitoring confined aquifers, the purging device should be placed in the upper portion of the screened interval (Figure 6-4). The sampling device should be placed in the screened interval.

The volume of water removed is dependent on how quickly the well waters equilibrate to the physical and chemical conditions in the aquifer. The parameters of pH, temperature and specific conductance are easily measured in the field and will adequately indicate when representative formation waters are entering the well. The purge volume can be calculated as the volume of water evacuated from the well from beginning of purging until measurements of the parameters in the purge water stabilize. Once

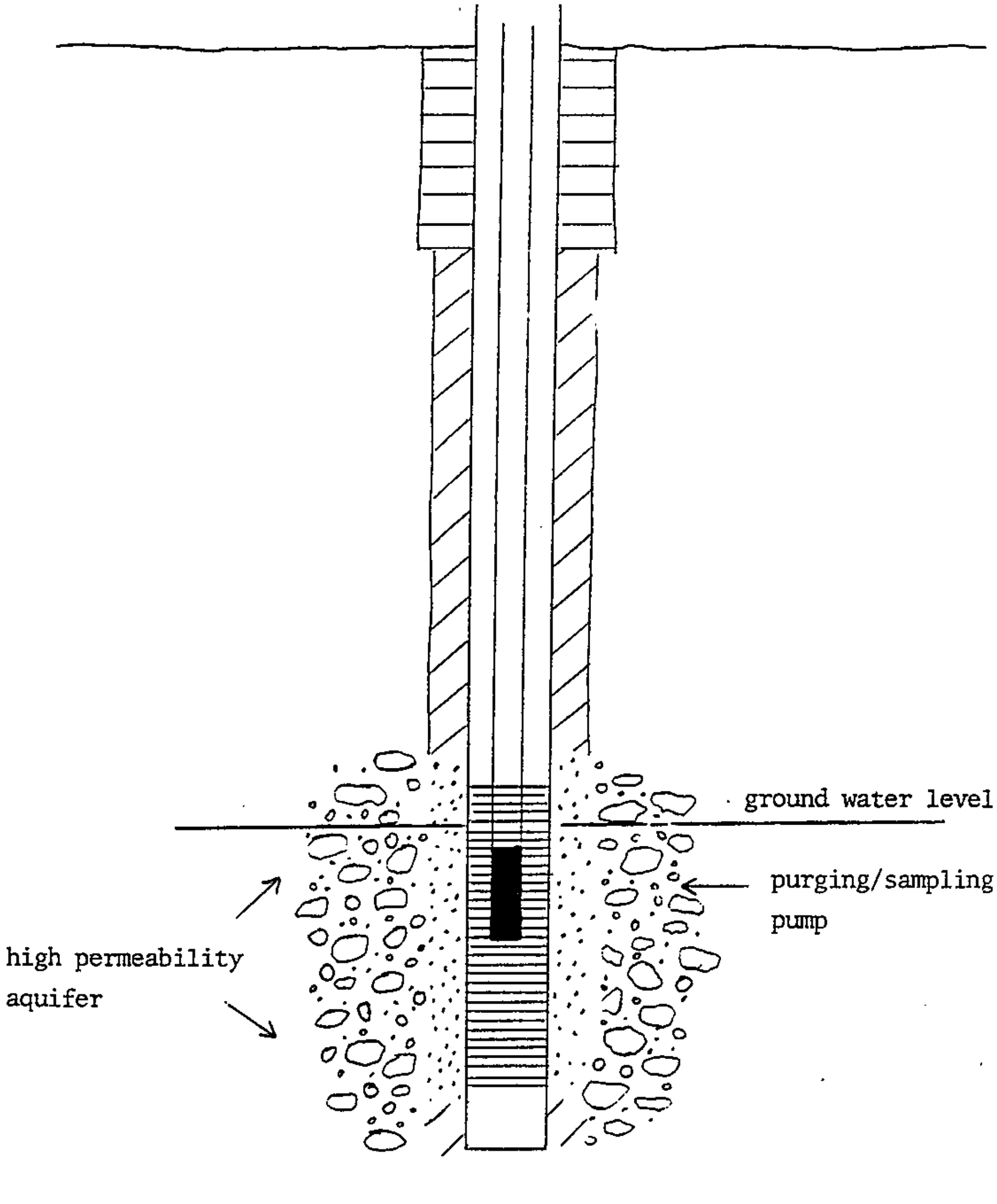

Figure 6-2. Pump Placement in High Permeability Aquifer.

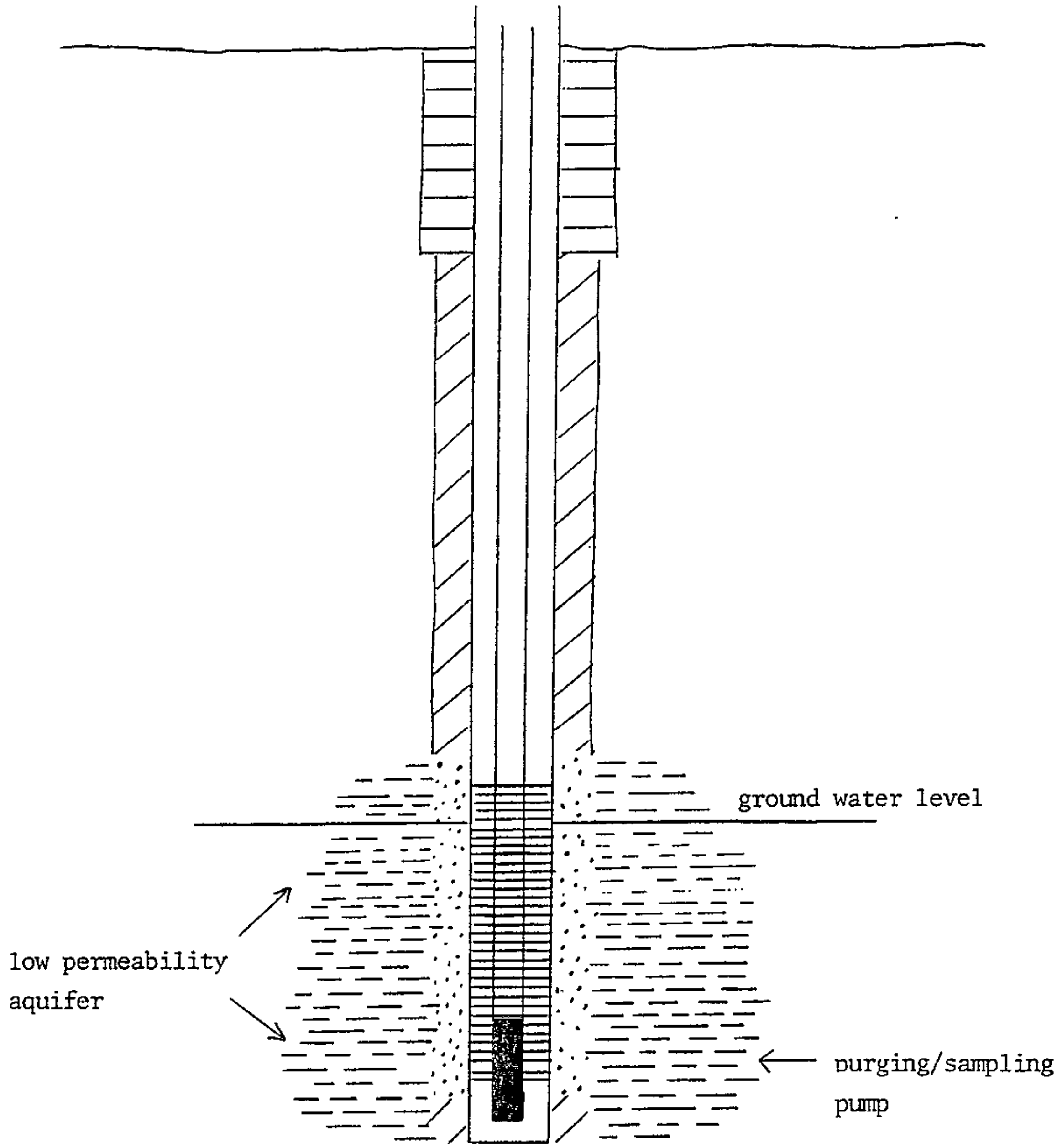

Figure 6-3. Pump Placement in Lower Permeability Aquifer.

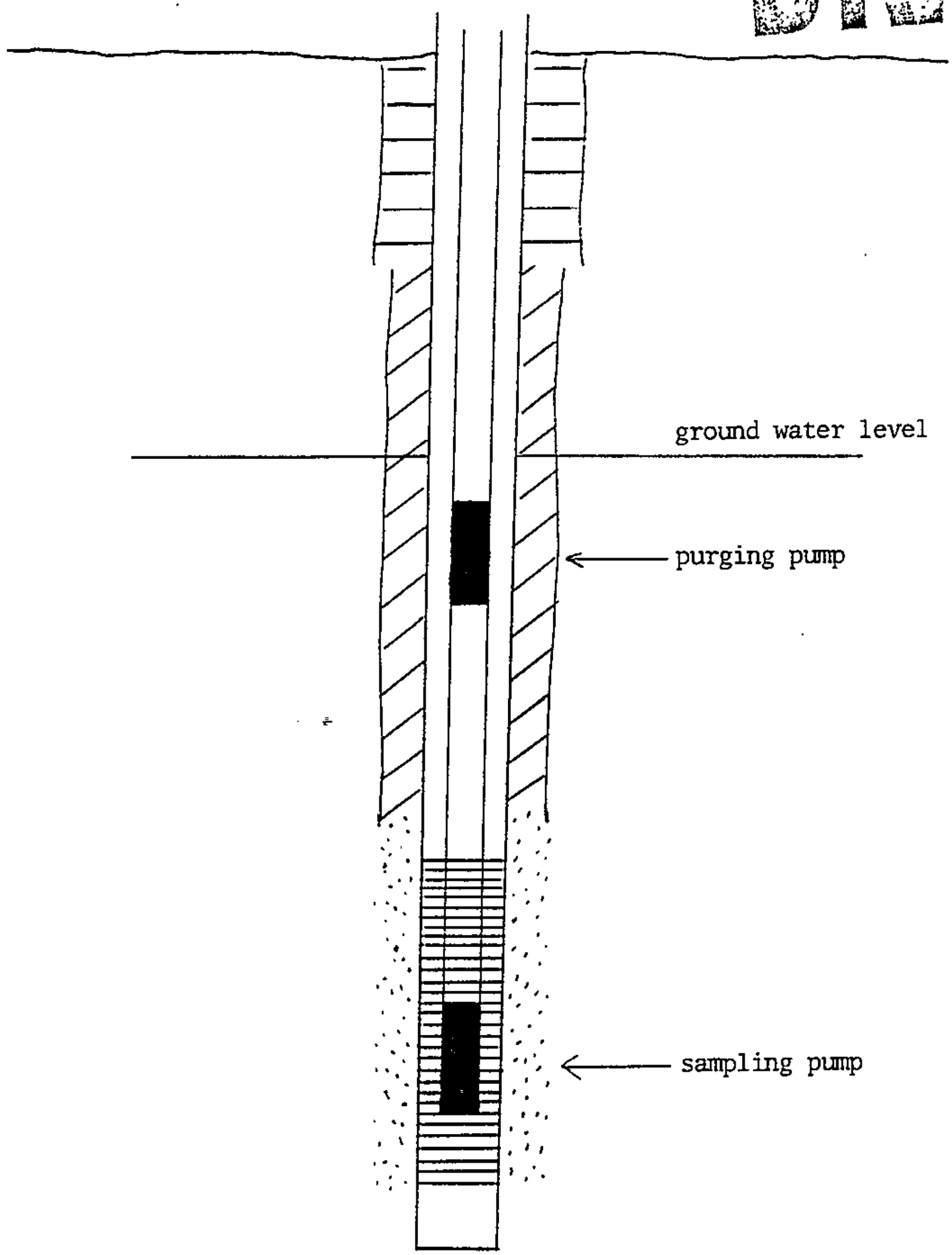

Figure 6-4. Pump Placement in a Lower Unit of an Unconfined Aquifer or in a Confined Aquifer.

established, the purge volume can be utilized during subsequent sampling periods if the depth to water in the well remains relatively constant.

Various types of equipment are available to purge wells, however the purging equipment capabilities should be matched to the aquifer and well characteristics (USEPA, 1986a). The depth and size of the well and the permeability of the aquifer should be considered in selecting purging equipment. Deep monitoring wells in highly permeable formations are not appropriate settings for low volume or labor intensive purge systems such as bladder pumps and bailers. Shallow monitoring wells in low permeability units are inappropriate for high volume purging systems. In many ground water monitoring programs, the equipment used for purging and sampling is the same. Therefore, careful consideration must be made of the requirements of the purging and sampling equipment.

6.2.3 Sample Collection Methods

The methods and materials used to withdraw a sample from a monitoring well should be selected based on the constituents to be analyzed for, and as previously discussed, the size of the monitoring well and aquifer characteristics. Ground water generally occurs under temperature, pressure, gas content and reduction-oxidation (redox) conditions which differ from surface waters (Lindorf et al., 1987). Pressure differentials and aeration resulting in gas-exchange and/or degassing, can adversely affect the chemical equilibria and redox conditions of the sample (NCASI, 1982). Ground water contaminants may sorb onto or leach out of sample device materials. The devices with the greatest utility for obtaining a broad spectrum of samples are those which minimize agitation, reduce or eliminate sample contact with the atmosphere, and are constructed of materials that are highly resistant to leaching or sorption of chemical constituents.

To monitor the constituents specified in the MFS, the sampling device can be constructed from PVC, fluorocarbon resins (PTFE, teflon, FEP, PFA), stainless steel, or polypropylene. Many sampling devices are available to meet the requirements of specific hydrogeologic conditions and monitoring needs. Bailers, gas operated bladder pumps, peristaltic pumps, mechanical lift pumps and electric submersible pumps are the most commonly used purging/sampling systems in the state.

If the sampling objective is to include analysis of volatile organic or base-neutral-acid constituents, additional consideration should be given to the selection of the sampling device (Barcelona et al., 1985). Volatile organics are highly susceptible to losses from sample aeration and air contact. The effects are particularly important when small quantities (i.e. low parts per billion levels) are environmentally significant (NCASI, 1982). Organic compounds may sorb onto or leach out of sample device materials. Phthalates are commonly found in base-neutral-acid analysis from wells with PVC screens. Sampling device materials are limited by the same constraints noted for well casing and screen materials (see Section 5.2.1). Bladder pumps or mechanical lift pumps constructed of PTFE or stainless steel meet the requirements for obtaining volatile organic or base-neutral-acid samples.

6.2.3.1 Bailers A bailer is a collection tube with a check valve at the base. Bailers are commonly constructed of PVC, stainless steel and fluorocarbon materials. Water generally enters the bailer through the check valve in the bottom, however some bailers must be submerged to fill through a top opening. Bottom filling bailers are generally preferred because the turbulent air/water mixing when filling the bailer is limited. Care should be taken when sampling to slowly lower the bailer into the water to minimize turbulence. Bottom filling bailers also may be used with a bottom emptying device that further limits air/water contact. Additional care is needed to keep the bailer line from dragging on the ground to avoid introducing contaminants to the well. The bailer line should be replaced after sampling each well. The bailer must be washed in a laboratory detergent solution and triple rinsed with deionized water between wells. If the ground water is contaminated additional nitric acid rinse and acetone rinse steps are recommended. Bailers are comparatively inexpensive, relatively easy to clean and easily portable. However, purging large volumes or sampling deep wells is labor intensive and the potential for introducing contamination is relatively high.

6.2.3.2 Bladder Pumps

Bladder pumps are driven by air pressure that is applied to the outside of a flexible membrane bladder contained inside the pump housing. The pressure causes the bladder to squeeze together, shutting a bottom check valve and pushing sample water out of the bladder, passed a top check valve and into the sample tubing. The air pressure is then released and the bladder refills through the bottom check valve. The system requires a pressurized air source, either air tanks or a compressor to operate. Bladder pumps lift small quantities of water and therefore purging with them can be a lengthy process. However, these pumps produce high quality representative and consistent samples. The pumps are best utilized as dedicated systems for individual wells. Nondedicated pumps including sample tubing must be washed and rinsed between wells. The pump requires occasional service. The periodicity of the pump maintenance schedule is dependent on the depth of the pump placement and turbidity of the well water.

6.2.3.3 Peristaltic Pumps

Peristaltic pumps have been used effectively in shallow aquifers primarily as a purging device followed by well sampling with a bailer. The pump operates by inducing a vacuum on the flexible tube by means of rollers progressively squeezing the tubing. The tubing usually is a silicon rubber base to withstand the squeezing applied by the rollers. Silicon tubing has a high sorption capacity for organics and therefore samples should be obtained through other devices. Monitoring of pH, temperature and specific conductance are easily done with this system. The system is limited to the depth of suction lift of water, which minus system inefficiencies results in a maximum lift of about 25 feet.

6.2.3.4 Mechanical Lift Pumps

Mechanical lift or positive displacement pumps operate by means of a piston lifting purge or sample waters passed lower and upper check valves through the pump housing and into the sample tubing. This old technology has been upgraded by several manufacturers with state-of-the-art materials, using stainless steel and teflon components. The pump has purge rate capabilities only surpassed by electric submersibles. Pumping rate can be adjusted down during sample collection. A stable well head platform is necessary to mount the pump head and actuator device. Stroke adjustments and some calibration of the system are necessary during installation and continued maintenance of fittings/bushings is necessary.

6.2.3.5 Submersible Electric Pumps

Submersible electric pumps have been used for years in supplying drinking water from aquifers. These pumps can efficiently purge wells and with appropriate flow controls can yield samples acceptable for the MFS required constituents. The pumps are generally larger than 3.75 inches in diameter and must be dedicated to each well. Smaller diameter pumps are coming on the market. The pump should be constructed of inert materials so that chemical interferences do not occur. In deep wells and high permeability aquifers, these pumps have the ability to efficiently purge wells and also supply ground water samples. Electric submersibles have been utilized in combination with bladder pumps as purging and sampling pumps, respectively when sampling for organic constituents in deep wells.

6.2.4 Quality Assurance and Quality Control

Quality assurance (QA) and quality control (QC) procedures should be provided which cover two aspects, field sampling and laboratory analysis. The laboratory aspects of QA/QC procedures will be discussed in section 6.2.6. The objective of field QA procedures is to evaluate the level of variability introduced by the sampling and sample handling procedures. A single sample result may not indicate "true" ground water quality. Field blanks, trip blanks, duplicate or split samples may be necessary. The purpose for each type of QA sample is indicated below. To meet the needs of a solid waste ground water monitoring system, field blanks (if using a single sampling device for multiple wells), duplicate and occasional split samples should be a part of the QA procedures. Specific numbers of samples of each type will depend on the number of wells in the monitoring program and the potential for impacts to ground water from the facility. If ground water sample results indicate that the facility has or may be impacting ground water quality, then additional duplicate and split samples should be considered to evaluate the variability and concentration of the constituent.

Field or transfer blanks are used when a device (such as a bailer) is used to sample more than one well in the ground monitoring system. Decontamination (cleaning) procedures must be implemented to clean the device between wells. The field blank is a reagent grade water sample that is run through the equipment during the sampling event. The sample is analyzed to evaluate whether the cleaning procedures are adequate.

Trip or transport blanks consist of reagent grade water samples from the laboratory which is placed in the sample containers identical to those utilized in the field. The trip blanks are taken to the field and handled in the sampling procedure as if they were obtained at the well head. The primary purpose of trip blanks is to check for volatile organic constituents (VOC). The MFS does not require analysis of VOC, therefore under standard procedures trip blanks would not be necessary.

Field duplicates are taken to determine sampling and analytical variability. Field duplicates are particularly important when assessing whether a constituent concentration exceeds permit or drinking water standards. The duplicate samples should be taken simultaneously (from same bailer, if using a bailer). The samples should be handled identically but labeled as separate samples. Duplicates should be collected on various constituents at a frequency appropriate for the concerns of the monitoring project.

Replicate samples are used to determine the variability in concentration of a constituent in ground water. The samples are obtained at intervals while sampling the well. The samples should be handled identically but labeled separately.

Split samples are taken in several situations and are used to determine laboratory variability. Split samples may be taken by the facility, a regulatory agency or secondary sampling entity. The split samples are then sent to separate laboratories. VOC samples should be collected immediately one after the other filling each sample container to minimize loss of volatile gasses from the sample.

6.2.5 Chain-of-Custody

The purpose of the chain-of-custody procedure is to assure that the sample can be accounted for from the time that it is obtained in the field to the time that the laboratory completes the analysis and provides a data report to the facility. An example of a chain-of-custody sheet that is utilized by Ecology is provided in Figure 6-5. Note that the sheet provides for identification of the type and number of samples, and the sample identification number. The form also provides a mechanism to trace sample possession from the field through shipping to the laboratory. Chain-of-custody also includes the labeling and sealing of samples. A sample label is provided in Figure 6-6. Sample seals should be applied to individual containers or to sample coolers that will be in shipment or locked up to prevent tampering.

6.2.6 Laboratory Methods

At a minimum ground water samples must be analyzed for the parameters and constituents noted in Table 6-2 below. Laboratory methods have been specified in "Test Methods for Evaluating Solid Waste (USEPA, 1986b) except for total coliform which should be analyzed by method in "Standard Methods for the Examination of Water and Wastewater" (USEPA, 1979). Methods providing equal or lower detection limits will be acceptable.

9 2 1 2 4 6 7 0 2 3 7

State of Washington Department of Ecology

FIELD SAMPLE DATA AND CHAIN OF CUSTODY SHEET

Project Code: ____________ Account: ____________

Name/Location: ____________

Project Officer: ____________

☐ Enforcement/Custody

☐ Possible Toxic/Hazardous

☐ Data Confidential

☐ Data for Storet

Notes: ____________

Samplers: ____________

Recorder: ____________ (Signatures Required)

SOURCE CODE	MATRIX				#CONTAINERS & PRESERV			LAB NUMBER			STATION NUMBER	DATE				COMPOSITE ONLY					STATION DESCRIPTION
	Water	Sediment	Tissue	Oil	Unpress	H_2SO_4	HNO_3	Yr	Wk	Seq		Yr	Mo	Dy	Time	ENDING DATE Mo	Dy	Time	Type	Freq	

LAB NUMBER			DEPTH	Units	Type	COL MTD CD	QA CODE	TEMP DEG C	pH	CNDCTVTY umho/cm	MISCELLANEOUS
Yr	Wk	Seq									

CHAIN OF CUSTODY RECORD

RELINQUISHED BY: (Signature)	RECEIVED BY: (Signature)	DATE/TIME
RELINQUISHED BY: (Signature)	RECEIVED BY: (Signature)	DATE/TIME
RELINQUISHED BY: (Signature)	RECEIVED BY: (Signature)	DATE/TIME
RELINQUISHED BY: (Signature)	REC'V'D BY MOBILE LAB FOR FIELD ANAL.: (Signature)	DATE/TIME
DISPATCHED BY: (Signature) DATE/TIME	RECEIVED FOR LAB BY: (Signature)	DATE/TIME
METHOD OF SHIPMENT		

ECY 040-115

Laboratory Copy White · Project Officer Copy Yellow · Field or Office Copy Pink

Figure 6-5. Sample Chain-of-Custody Form.

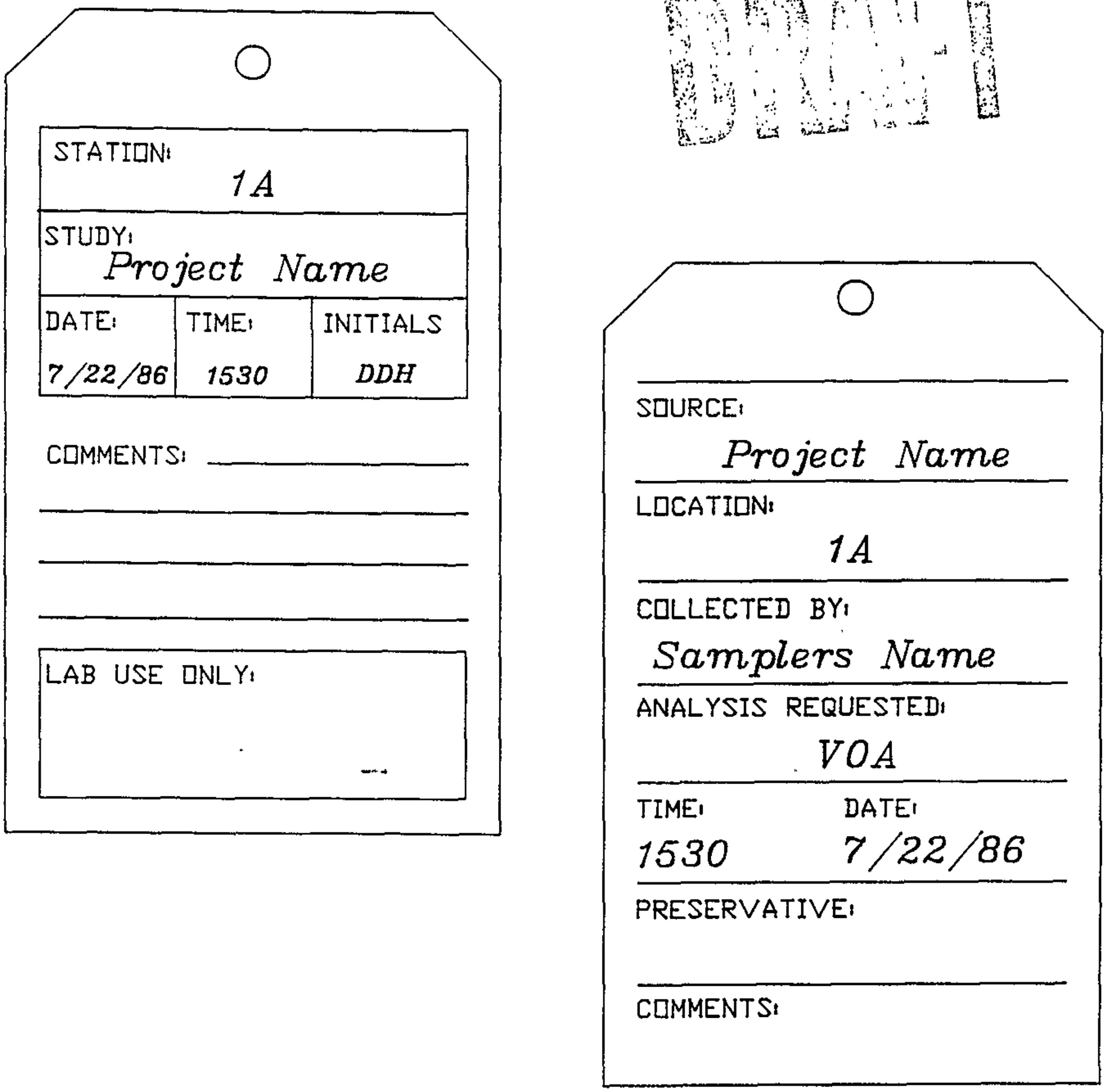

Figure 6-6. Sample Labels.

Measurement of pH, temperature and specific conductance parameters should be made in the field during the purging and sampling period. These parameters should be measured a minimum of three times at evenly spaced intervals during the sampling period. The laboratory should provide and have implemented a QA/QC program to verify the chain of custody control and the precision and accuracy of analytical results.

Table 6-2. Ground Water Monitoring Parameters and Constituents.

Parameters	Constituents
pH	chloride
temperature	nitrate, nitrite and ammonia
specific conductance	sulfate
chemical oxygen demand	dissolved iron
total organic carbon	dissolved zinc and manganese
total coliform	

7.0 DATA REPORTING AND STATISTICAL ANALYSIS

The analytical results for the constituents identified in Chapter 6 must be reported and evaluated to assess whether landfill leachates have impacted ground water quality. The assessment of ground water impacts is specified in the regulations as a statistical comparison of downgradient results (potentially contaminated ground water) to background water quality. There are many statistical methods to evaluate data. The appropriate selection of method is dependent on the quantity of data i.e., how many quarters of data are present in the data set, the data distribution, i.e., parametric or nonparametric, the number of upgradient and downgradient wells and the quality of the site hydrogeologic characterization data.

The ability of a statistical method to correctly identify ground water contamination when it has occurred is dependent on the size of the data set (number of sampling periods), the number of wells with which comparisons can be made, and the inherent variability of the constituent in the ground water system. Many of the solid waste landfills in the state are in the beginning stages of hydrogeologic characterization and establishing ground water monitoring programs. Generally the ground water monitoring systems are being installed to meet only the minimum of one upgradient and three downgradient wells. Therefore, ground water quality results are available from few wells over a brief period. The guidance in this chapter presents some general graphical techniques and simple statistical methods with which to evaluate water quality results. More sophisticated procedures have been considered and are discussed below. These methods may be applicable to the few facilities that have relatively larger data sets or numbers of wells.

7.1 Regulatory Reference Sections

The paragraphs below are from the MFS ground water monitoring requirements.

WAC 173-304-460 (2)(a) An owner or operator of a landfill shall not contaminate the ground water underlying the landfill, beyond the point of compliance.

WAC 173-304-490 (2)(f) The owner or operator shall use a statistical procedure for determining whether a significant change has occurred. The jurisdictional health department will approve such a procedure with the guidance of the department.

WAC 173-304-490 (2)(g) The owner or operator must determine ground water quality at each monitoring well at the compliance point at least quarterly during the life of an active area (including the closure period) and the postclosure care period. The owner or operator must express the ground water quality at each monitoring well in a form necessary for the determination of statistically significant increases.

WAC 173-304-9901 Maximum contaminant levels for ground water shall be those specified in chapter 248-54 WAC, as the primary drinking water standards.

7.1.1 Intent and Purpose of Regulation

The requirements set forth above identify three specific areas that must be addressed.

Ground water results must be expressed (reported) in a format such that an evaluation of water quality impacts can be made.

A statistical method must be utilized to compare upgradient data to downgradient data.

Contamination must be evaluated as exceeding primary drinking water standards.

The following sections will discuss the data report format and the statistical procedures which should be used to report and analyze the water quality results.

7.2 Data Report Format

Ground water monitoring data should be reported such that the data are easily reviewed by the health jurisdiction or Ecology regional office. A suggested report format has been provided on Figure 7-1. The data reported on this form are the laboratory analytical results for the parameters and constituents identified in Table 6-2 and any additional constituents identified by the jurisdictional health department. This format has been put together for reporting data from a single well for four quarters of data. The format should be expanded over time as additional data are collected so that a single data table has all monitoring data for a well. In addition to the reporting of raw data results, the owner/operator of a landfill should report summary statistics as identified in Figure 7-2. These summary statistics will be used in the graphical and statistical analysis discussed in the next section of this chapter.

7.3 Statistical Analysis of Ground Water Data

The standards require the use of a statistical procedure for determining whether a significant impact to ground water has occurred. The general concept of ground water monitoring in the regulations is to establish background or nonaffected ground water quality as a basis on which to statistically compare potentially affected water quality. For some facilities it is not possible to place ground water wells at upgradient locations because the landfills have been sited at the limits of the recharge area. Consequently, background conditions may include locations that are not upgradient of the facility.

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Ground Water Monitoring Data Report

Parameter	Units	Detection Limit	Well Number	Sample Date	Result
pH	-log H^+	0.01			
temperature	degree C	0.1			
specific conductance	umhos/cm	1			
chloride	ppm				
nitrate	ppm				
nitrite	ppm				
ammonia	ppm				
sulfate	ppm				

Figure 7-1. Ground Water Quality Data Report Format.

Ground Water Monitoring Data Report (continued).

Parameter	Units	Detection Limit	Well Number	Sample Date	Result
iron	ppm				
zinc	ppm				
manganese	ppm				
COD					
TOC	ppb				
coliform	mpn				
others as identified by the jurisdictional health department					
VOC's	ppb				
BNA's	ppb				
metals	ppb				

Figure 7-1 (continued). Ground Water Quality Data Report Format.

Parameter or constituent	Well Number	number of samples	*number of LTDL values	Mean Value	Median Value	F-Spread	Minimum value	Maximum value
pH								
temperature								
specific conductance								
chloride								
nitrate								
nitrite								
ammonia								
sulfate								
iron								
zinc								
manganese								
COD								
TOC								
coliforms								
others as identified by the jurisdictional health department								
VOC's								
BNA's								
metals								

*number of LTDL values - number of less than detection limit values

Figure 7-2. Ground Water Monitoring Data Summary Statistics.

Until recently, the standard statistical procedure to detect ground water contamination has been the Cochran's Approximation to the Behrens Fisher Student's t-test as recommended by EPA in the hazardous waste regulations. The test has received much criticism because the assumptions may not be valid for the data and because of the potential to indicate false positives (that is, the indication that ground water contamination has occurred when indeed it has not), or false negatives (that is, the indication that ground water contamination has not occurred when indeed it has).

Several statistical procedures were reviewed to establish a preferred method for evaluating solid waste ground water monitoring data. The procedures reviewed are those identified as alternatives to the student's t-test (USEPA, 1988; Doctor et al., 1986; Splitstone, 1989). These procedures included tolerance intervals, control charts, alternative student's t-tests, and parametric and nonparametric analysis of variance. A procedure that utilizes order statistics (Goodman, 1987) was also reviewed. Goodman proposed this method to review State of Wisconsin solid waste program ground water monitoring data.

The criteria used to evaluate the procedures are as follows.

The procedure must be robust for false indications of contamination or noncontamination. That is, the method must not have high false positive or false negative rates.

The statistical assumptions of the procedure must be valid for the data evaluated.

The procedure must be relatively easy to apply and results should be expressed in a form that is readily understandable.

The procedure must be able to accommodate monitoring systems that have few wells and limited data sets at the present time.

7.3.1 Student's t-Test

The basic concept of the student's t-test is to state an hypothesis to be tested called the null hypothesis, and an alternative hypothesis. The statistical analysis is set up to either accept the proposed null hypothesis, or reject the null hypothesis and accept the alternative. The basic form of the null hypothesis is that the constituent result to be tested is equal to or a member of the background population. The alternative hypothesis is that the result is not equal to or a member of the background population. The statistic used to evaluate this hypothesis may either over or underestimate the variance in the population (Splitstone, 1989). One may then conclude that contamination has occurred when it really has not, or that no contamination has occurred when ground water impacts from the facility have indeed occurred. The procedures assume data that are normally distributed, with samples that are independent of each other and randomly obtained. The student-test has been widely criticized for the potential violation of the statistical assumptions, low power when assumptions are not met, increasing false positive rates as the test is completed over the landfill life, incorrect comparisons of variability in space and over time, and with variability in chemical analysis.

7.3.2 Parametric and Nonparametric Tolerance Interval and Control Charts
Parametric and nonparametric tolerance interval and control charts have a great deal of usefulness for analysis of ground water data. They provide graphical presentations of the reduced data which provide very good visual evaluations. The methods require many quarters of data with multiple upgradient wells to set the interval or control chart level for a given constituent or parameter. Few, if any of the Solid Waste landfill monitoring systems have the number of wells and sampling periods in there records that provide the data required by these methods. The methods may be appropriate in the future as more wells are completed and the number of reporting dates in a data set expand.

7.3.3 Analysis of Variance (ANOVA)
ANOVA methods are applied to evaluate the source of variations in ground water quality data attributable to well location, time of sampling and measurement errors. These methods, as with tolerance intervals and control charts, require large data sets with multiple upgradient wells to meet the test method of defining the magnitude and source of variation in analytical results. The ANOVA methods provide powerful techniques in ground water data analysis, however have little application in most current solid waste ground water monitoring programs in the state because of the limited number of wells and data reporting periods.

7.3.4 Order Statistics
Order statistics were developed to provide simple computational methods to characterize and investigate exploratory data. The method reported in Goodman (1987) and Fisher (1989) was reviewed and subsequently selected for use in analyzing solid waste ground water monitoring data. The statistics are easy to compute and can be graphically represented. The graphical representation of the data along with concentration versus time plots give a very strong visual representation of the ground water quality data. And, the background or unaffected water quality to which downgradient data are compared can include not only upgradient wells but may also include unaffected cross gradient and downgradient wells. The method, as with other methods can be used in combination with several procedures to evaluate seasonality in the monitoring data and analyze for trends. The analysis of seasonality and trends require data sets that extend over a several year period.

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7.4 Statistical Procedures of Selected Method

The procedure utilizes the analytical results of several water quality constituents or parameters to confirm the presence, absence or possibility that ground water has been contaminated. The mathematical operations involved include ordering data from lowest to highest reported values and simple addition, subtraction and division. The method will be used to generate statistical parameters to be used in a graphical presentation of the data known as "box plots" (Hoaglin et al., 1983). The box plot is a very useful tool to visually evaluate water quality data from all wells at a facility. Time series plots of the data values will also be used to visually inspect for trends and to compare with the box plots.

7.4.1 Background on Statistical Parameters

In order statistics the median is used to describe the central location of the population, similar to the mean (average) value in other statistical methods. The F-spread or fourth spread in order statistics is the measure of the variability in the water quality results, similar to the standard deviation in other statistical methods. Hoaglin et al. (1983) provide a thorough discussion of order statistics and the concepts presented in this section.

The concepts of the rank and depth of an individual result within a data set are utilized to calculate the median and F-spread for the site. First, the data for each well and the site as a whole must be ordered from the least value to the highest value for the given constituent. Then the rank of a specific analytical result can be defined by counting up from the lowest value (upward rank) or down from the highest value (downward rank). For any analytical result, the upward rank plus the downward rank is equal to the number of analytical results plus 1. The depth of an analytical result is the smaller of the upward rank or the downward rank.

The median value is the value at which the upward rank and downward rank are equal. For data sets in which the number of analytical results are even, the depth of the median value is calculated as,

$$\text{depth of the median} = (n + 1) / 2 \quad \text{where;} \qquad \underline{\text{equation 7.1}}$$

n = number of analytical results. For data sets in which the number of analytical results are odd, the depth of the median value is calculated to be a fraction, 1/2. Two examples illustrate the calculation of the depth of the median value in the data set. When $n = 5$, the depth of the median is $(5 + 1) / 2 = 3$, so the median value of the data set is the third value in upward or downward rank (remember that the depth of the median in the data set can be counted from either the lowest or highest value). When $n = 6$, the depth of the median is $(6 + 1) / 2 = 3\ 1/2$, so the median is interpolated to be half way between the third and fourth values in the data set.

The median is a measure of the center of the data set and divides the data set such that half of the analytical results are greater in magnitude and half of the results are lesser in magnitude. An alternative way to state this is that the median is the depth of half. The depth of the median is used to calculate a measure of the spread or variance of the data set as follows,

depth of fourth = ([depth of median] + 1) / 2 where; <u>equation 7.2</u>

the brackets [x] stand for the largest integer not exceeding x. In other words, drop any fraction from the depth of median, add 1 and divide by 2 (Hoaglin et al., 1983). There are two depth of fourth values calculated in this way, the depth from the lowest analytical result counting upward and the depth from the highest analytical result counting downward. The analytical results corresponding to the upper and lower depth of fourths are used to compute the F-spread or fourth spread as follows,

$$\text{F-spread} = AR_{\text{upper fourth}} - AR_{\text{lower fourth}}$$ where; <u>equation 7.3</u>

$AR_{\text{upper fourth}}$ = analytical result of the depth of the upper fourth,

$AR_{\text{lower fourth}}$ = analytical result of the depth of the lower fourth.

<u>Example 7.1</u> Four monitoring wells with four quarters of chloride results are reported below. Calculate the median chloride value for all wells and the F-spread for each well.

Well #	first	second	third	fourth	comments
	quarters (Chloride ppm)				
1	15	27	23	18	upgradient
2	25	17	19	22	downgradient
3	55	80	60	65	downgradient
4	30	18	34	29	downgradient

Step 1. Rank all results from lowest to highest as follows:

depth:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
value:	15	17	18	18	19	22	23	25	27	29	30	34	55	60	65	80

Step 2. Count total number of results, n. n = 16

Step 3. Calculate depth of median and site median chloride value.
depth of median = (n + 1) / 2 = (16 + 1) / 2 = 8.5

The site median analytical value for chloride is interpolated to be half way between the depths of 8 and 9 or (25 + 27) /2 = 26.

Step 4. Order the chloride results from lowest to highest for each well, calculate the upper and lower depth of fourth values, and take difference to compute F-spread.

depth of fourths = ([depth of median] + 1) / 2
([2.5] + 1) / 2 = (2 + 1) / 2 = 1.5

well #	depth:	1	1.5	2	2.5	3	3.5	4
1	value:	15		18		23		27
2		17		19		22		25
3		55		60		65		80
4		18		28		30		34
			depth of lower fourth		depth of median		depth of upper fourth	

$$\text{F-spread} = \text{AR}_{\text{upper fourth}} - \text{AR}_{\text{lower fourth}}$$

well #	F-spread
1	(27 + 23)/2 - (15 + 18)/2 = 25 - 16.5 = 8.5
2	(25 + 22)/2 - (17 + 19)/2 = 23.5 - 18 = 5.5
3	(80 + 65)/2 - (55 + 60)/2 = 72.5 - 57.5 = 15
4	(34 + 30)/2 - (18 + 28)/2 = 32 - 23 = 9

7.4.2 Data Standardization

The response of several indicator constituents and parameters will be used to evaluate impacts of the landfill on ground water. Comparability across constituents and parameters will be achieved by standardizing values to a common scale. The standardized values are plotted on a common scale for comparison and evaluation of water quality results. The steps to standardize the ground water quality results are presented below. Keep in mind that standardization is used to facilitate cross referencing analytical results from several constituents or parameters and allows the results to be presented on the same graphical scale.

All water quality results for a given constituent or parameter are calculated with the same summary statistics for that constituent at the site. The standardized value is calculated by the following equation:

$$SV = (AR - M_{site}) / \text{F-spread}_{\text{site median}}$$ where; <u>equation 7.4</u>

SV = standardized value,

AR = analytical result for a constituent or parameter,

M_{site} = median value of the constituent for all wells, and

$\text{F-spread}_{\text{site median}}$ = site median fourth spread statistic.

<u>Example 7.2</u> Calculate the standardized chloride values for the wells from example 7.1.

Step 1. Order the F-spread values for each well (example 1, step 4) from lowest to highest and calculate the median F-spread statistic.

depth:	1	2	3	4
F-spread statistic:	5.5	8.5	9	15

depth of median F-spread = (4 + 1)/2 = 2.5
median F-spread statistic = (8.5 + 9)/2 = 8.75

Step 2. Standardize the chloride values using equation 7.4.

	quarters				
Well #	first	second	third	fourth	comments
	(standardized chloride values)				
1	-1.26	0.11	-0.34	-0.91	upgradient
2	-0.11	-1.03	-0.80	-0.46	downgradient
3	3.31	6.17	3.89	4.46	downgradient
4	0.46	-0.91	0.91	0.34	downgradient

The standardized values that result will be negative if the original analytical value is less than the site median statistic and positive if the original value was greater than the median. Dividing by the F-spread scales the standardized value to a common scale on which to plot the result. Keep in mind through this computing process that the objective is to plot several constituents or parameters on a common scale.

7.5 Boxplots, Time Series Plots and other Graphical Presentations
The following sections will provide a discussion of the use and application of graphical tools in evaluating ground water quality data. Boxplots and time series plots are recommended to present and evaluate the water quality results. Bar graphs and plume maps placed on a site map can be informative representations of the spatial variability in ground water quality.

7.5.1 Boxplots
The boxplot is an economical graphical method of presenting the constituent summary statistics. The median value along with an approximated 95% confidence interval about the median, the spread of the data and extreme values can be presented in a single format as in the Figure 7-3. Figure 7-4 presents several example boxplots produced with software programs. The boxplots are constructed using the median and F-spread as in Figure 7-3. Outliers limits are designated as the outer twenty percent of the distribution by the STATVIEW 512+ program (see Figure 7-4(a)). STATGRAPHICS (see Figure 7-4(b)) defines outliers to be + or - 1.5 times the F-spread, as defined by Hoaglin et al. (1983) (see Figure 7-3).

The Boxplot

```
             ----------------
      -------I    ( + )    I-------       *     *     *
             ----------------
```

Boxplot symbols:

- The + shows the location of the sample median.
- The ( ) indicate the approximate 95% confidence interval within which the population median is expected to occur. The interval is estimated as +/- 1.58 (F-spread / $n^{1/2}$).
- The I I or box "ends" show the upper and lower fourth-spread values and bracket 50% of the data.
- The ------- extend to the most extreme data values unless the extreme values fall beyond the outlier cutoffs[a], a specified distance from the median.
- The * symbol represents extreme values. When constructing the boxplot the actual extreme value is placed on the graph.

a Hoaglin et al. (1983) found in experience with exploratory data sets that the limits for outlier cutoffs can be set as follows:

lower cutoff = $AR_{\text{lower fourth}}$ - 1.5(F-spread)

upper cutoff = $AR_{\text{upper fourth}}$ + 1.5(F-spread)

Figure 7-3. The Boxplot Format and Symbols.

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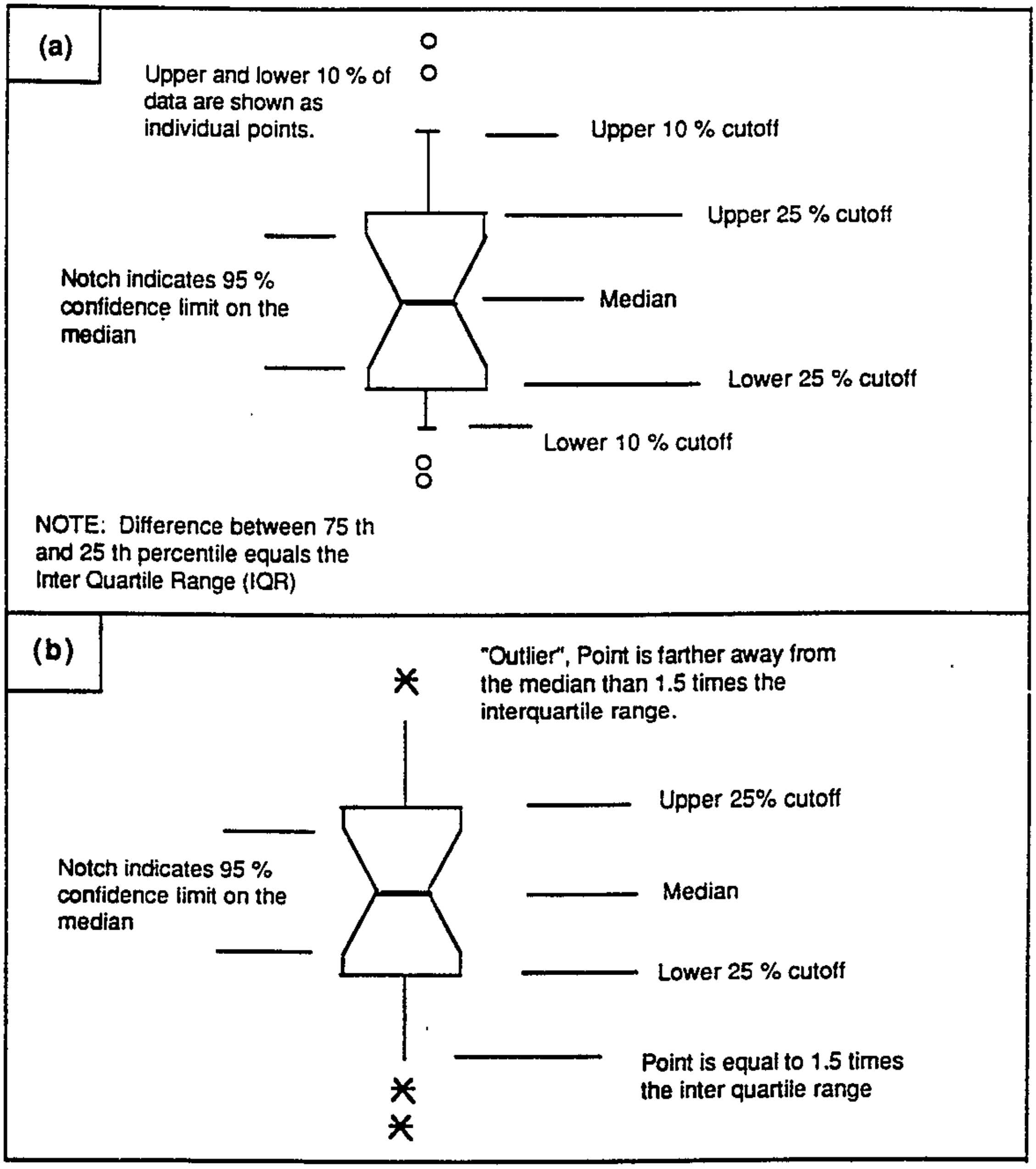

Figure 7-4. Boxplots Constructed by Software Programs, STATVIEW 512+ (a) and STATGRAPHICS (b) (taken from Fisher, 1989).

7.5.2 Time Series Plots

Time series plots are graphical presentations of the constituent concentrations or parameter values over time (Figure 7-5). The usefulness of these plots are in comparing with the boxplots and in analyzing the data for trends and seasonal fluctuations. There are several statistical methods which can be applied to the data sets to evaluate for trends and seasonality. The Mann-Kenndal test for trend assesses the relative magnitudes of the concentration data with time (Goodman, 1987). Doctor et al. (1986) recommend a minimum of two years baseline sampling for assessing long-term trends. Several researchers have modified the Mann-Kenndal test to evaluate seasonality in data sets. Goodman (1987) found that the seasonal test requires at least ten years of quarterly data for adequate power to detect seasonal trends. Few landfills have data sets of several years or more to make these type of evaluations, therefore the methods are referenced here for possible future use.

7.5.3 Bar Graphs and Plume Maps

Bar graphs are useful in evaluating the spatial nature of ground water quality data. Figure 7-6 shows ground water quality results from several constituents at a dangerous waste facility. These graphs are most useful when evaluating several constituent results. The bar graphs provide a good visual presentation of individual quarters of ground water quality data. Another useful method of presenting ground water quality data is the concentration isopleth map or plume map (Figure 7-7). The isopleth or concentration contour line shows the area within which the ground water contaminant levels exceed the given concentration. Consideration of any regulatory or health limits and background levels should be made in the selection of isopleth line concentration.

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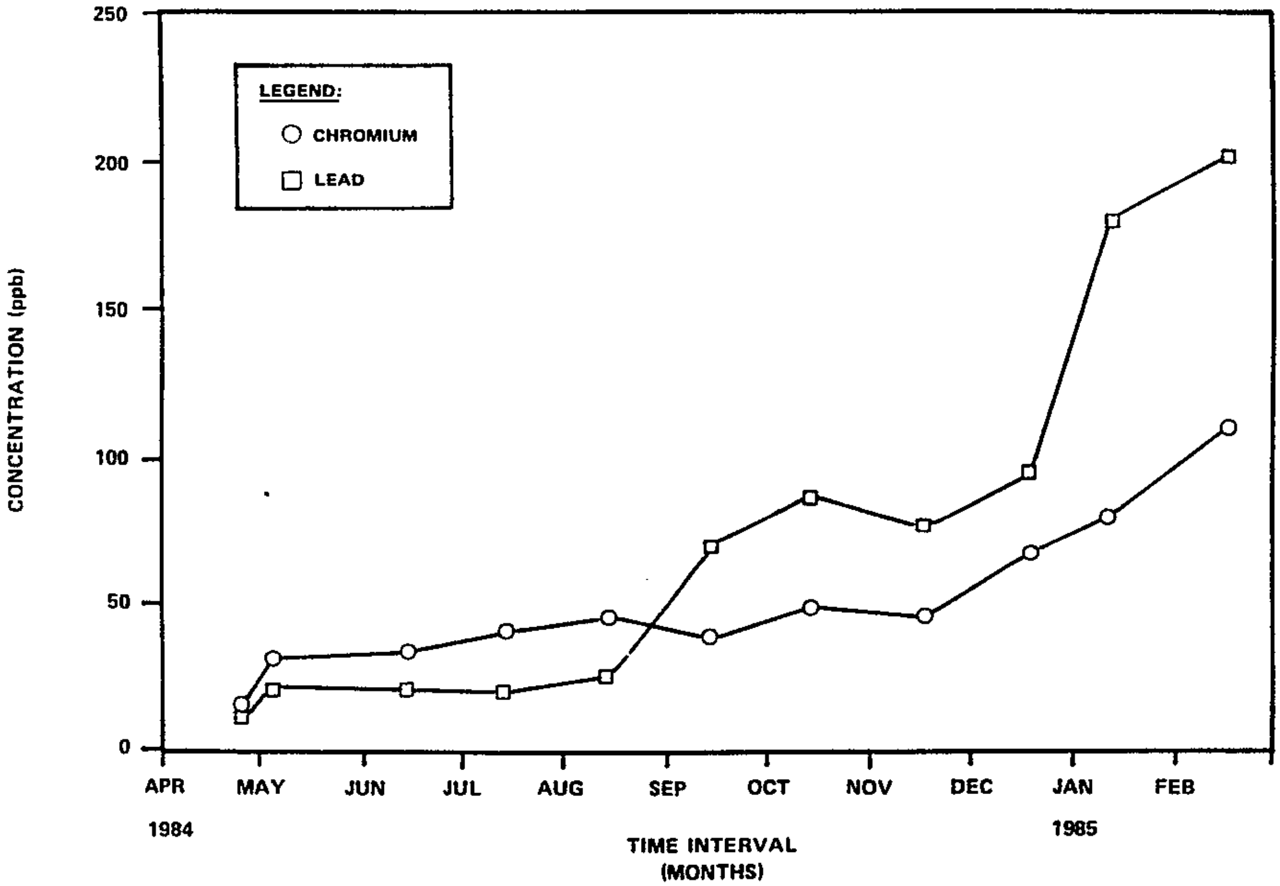
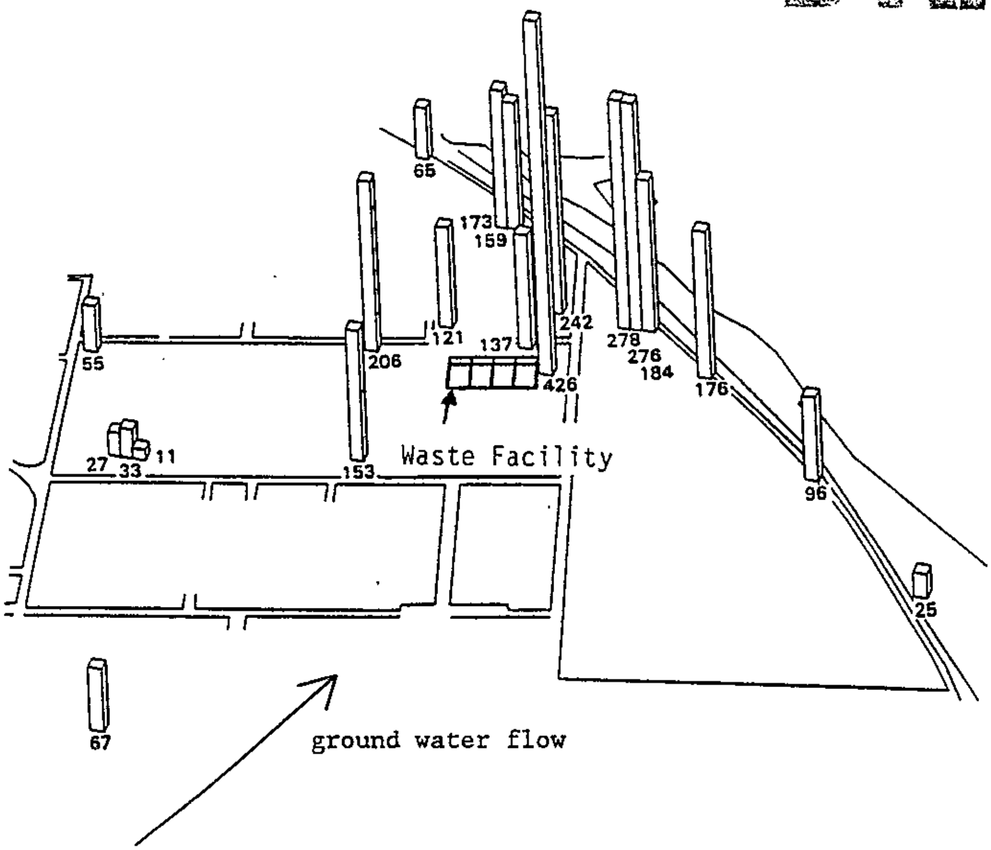


Figure 7-5. Chromium and Lead Concentrations Over Time (taken from USEPA, 1986a).



Legend
Constituent: Chromium
Units: ppb
Height of bar indicates constituent concentration
Bars located at monitoring wells

Figure 7-6. Bar Graphs of Chromium Concentrations from Monthly Samples at a Hazardous Waste Facility (modified after USDOE, 1987).

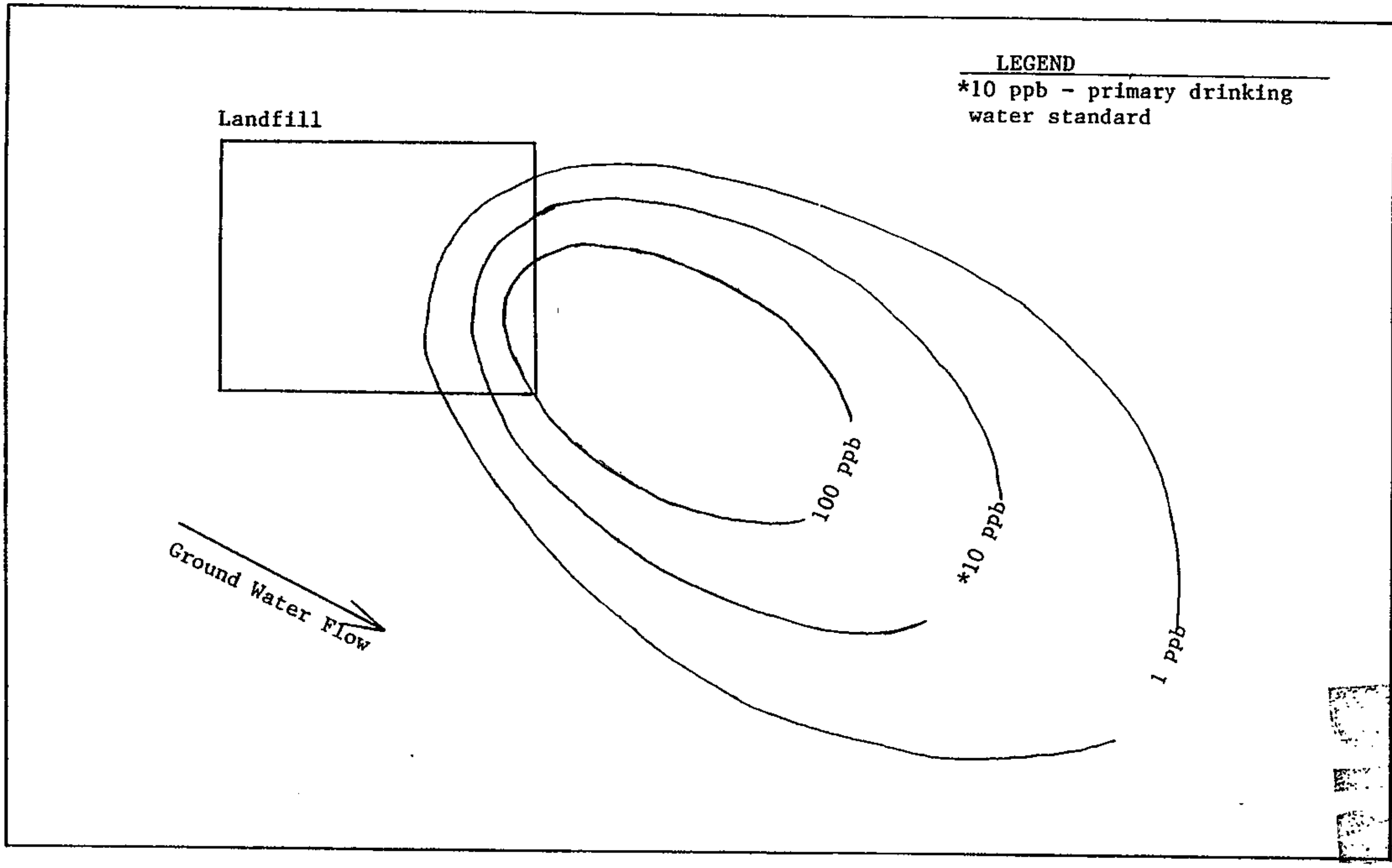


Figure 7-7. Generalized Ground Water Contaminant Plume Map.

7.6 Data Evaluation

The first step in analyzing ground water quality data is to tabulate the data in the format provided in Figure 7-1. An inspection of the data for a constituent within a single well should then be completed over the several quarters of ground water quality results. Time series plots for the constituent results should be updated and reviewed for any trends that may be evident.

Bar graphs should be constructed to graphically compare the constituent results for all wells in the ground water monitoring well network. In situations where several aquifers are monitored, bar graphs for each aquifer should be constructed. These should be reviewed for any indications of ground water quality impacts that may be evident.

The data for constituents indicating potential trends (from the time series plots) and the data that indicate potential down gradient impacts from the facility should be standardized and boxplots constructed. The boxplots should be evaluated to assess whether the results from downgradient wells differ from the background wells. The results from several constituents should be used to determine whether the landfill has impacted ground water quality. However, if only a single constituent result indicates potential impacts, there is justification to review other constituent data. The jurisdictional health department should also consider the need for sampling for additional constituents including volatile organics, base/neutral/acids, pesticides, and priority pollutant metals.

7.6.1 Example Boxplots

Substantial portions of this discussion were taken from Goodman (1987). Figures 7-8, 7-9, and 7-10 provide illustrations of hypothetical landfills which represent several ground water quality conditions. Figure 7-8 shows boxplots of upgradient wells with little difference in water quality. The boxplots indicate a site median value of about 20 AR units which corresponds to a standardized value of about zero. The box "ends" and "tail" lengths are reasonably symmetrical about the median value for each well. This indicates approximately equal distribution of low and high values and little skew to the data. The confidence intervals are used to infer information about the population median value, i.e. the median ground water quality result for all possible samples from a well. The sample median is indicated by the "+". The confidence interval indicates the certainty with which the population median can be estimated from the sample median and variation. The probability is about 95% that the population median value lies between the "( )", parenthesis. The AR and standardized scales show that the absolute concentrations of this constituent in both upgradient and downgradient wells are low. Therefore, the wells indicate no impact from the landfill.

Figure 7-9 shows boxplots of wells with water quality changing slightly in the downgradient wells. The site median value in upgradient wells is about 20 AR units and increases in downgradient wells to about 35 AR units. One

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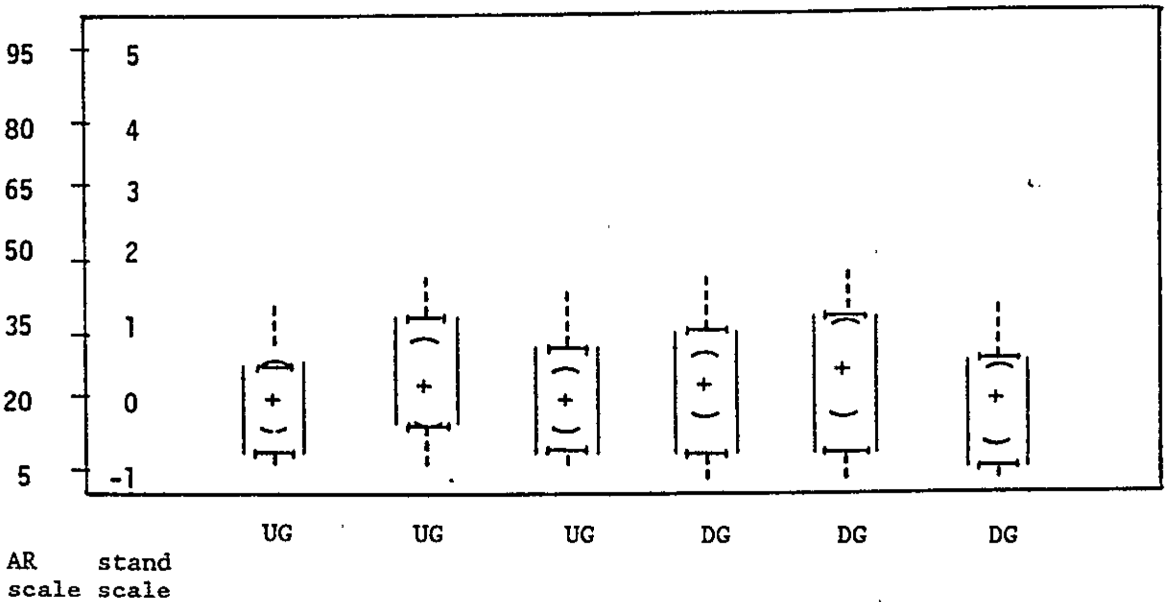
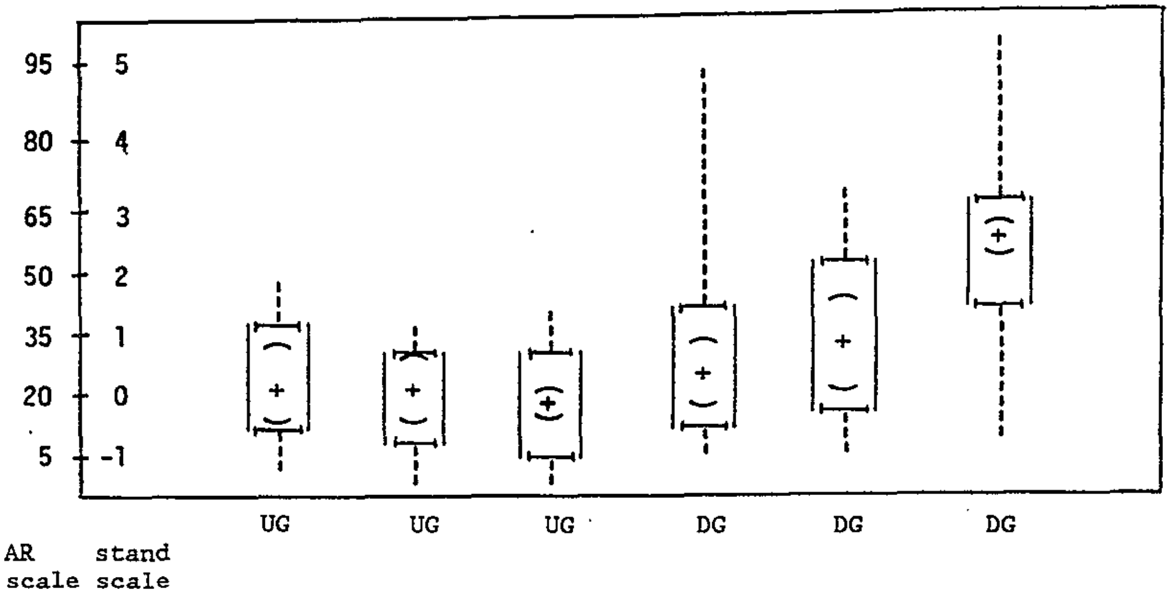


LEGEND:

AR scale - Analytical Result scale
stand scale - standardized value scale
UG - upgradient well
DG - downgradient well

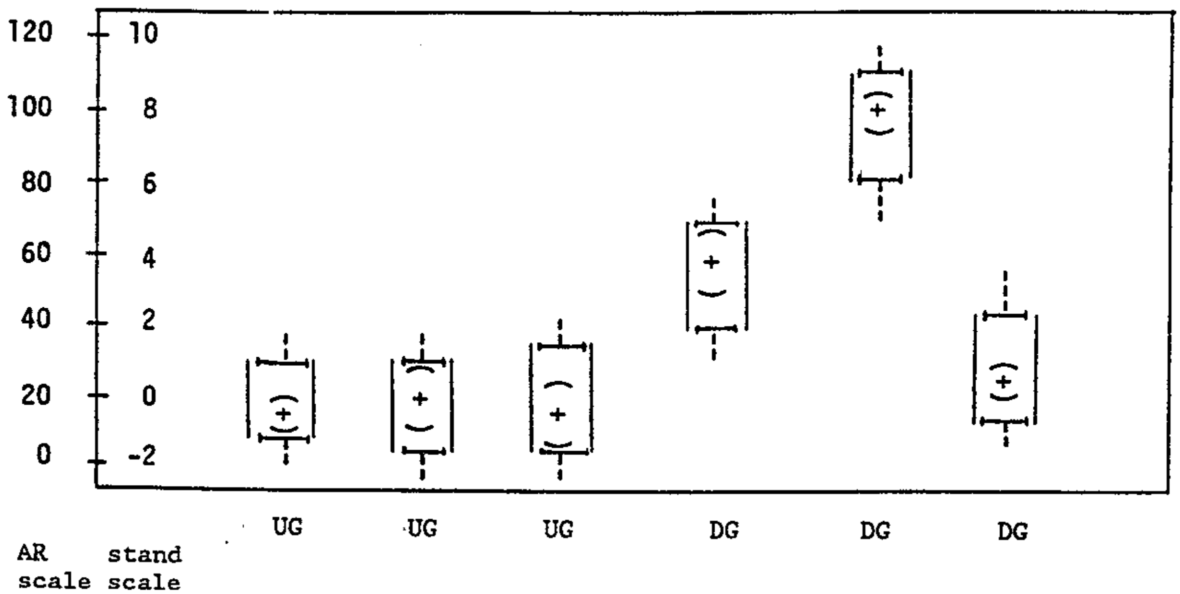
Figure 7-8. Boxplot of Hypothetical Landfill Wells with no Ground Water Quality Impact (modified after Goodman, 1987).



LEGEND:

AR scale - Analytical Result scale
stand scale - standardized value scale
UG - upgradient well
DG - downgradient well

Figure 7-9. Boxplot of Hypothetical Landfill Wells with Possible Ground Water Quality Impact (modified after Goodman, 1987).



LEGEND:
AR scale - Analytical Result scale
stand scale - standardized value scale
UG - upgradient well
DG - downgradient well

Figure 7-10. Boxplot of Hypothetical Landfill Wells with Highly Probable Ground Water Quality Impact (modified after Goodman, 1987).

downgradient well shows a much longer tail length toward higher concentrations, while the other two wells indicate a wider confidence interval and greater spread in the tail lengths. In this case, the time series plots must be utilized in conjunction with the boxplots to evaluate the downgradient wells to assess whether increasing trends or more random variation are causing the changes in downgradient well concentrations.

The boxplots on Figure 7-10 indicate differences in the population median values between the upgradient wells and two of the downgradient wells. The differences in the sample median values are high and the confidence intervals do not overlap. This is strong evidence that the median values are statistically different. The boxplots indicate fairly stable water quality conditions, as interpreted from the low spread and fairly short tail lengths. This suggests that water quality may have been impacted when ground water monitoring began.

7.6.2 Evaluation of Time Series Plots and Boxplots

Fisher (1989) provides an example of the use of boxplots and time series plots to evaluate a single ground water quality parameter (Figure 7-11). This example illustrates the utility of the boxplot in conjunction with the time series plot in visualizing the ground water data. Wells OB-6 and OB-13 are background wells for the facility, an unlined municipal landfill. Wells OB-10 and OB-11 are immediately adjacent and downgradient of the waste disposal area. Well OB-2 is adjacent to the site but near the upgradient limit of the waste disposal area. Well OB-17 is farther afield, downgradient of the facility. The time versus concentration plots for the adjacent and downgradient wells (OB-2, -10, -11 and -17) show increasing trends over time. Specific conductance levels have remained quite constant in the background wells OB-6 and OB-13.

The boxplots assist in more clearly defining water quality impacts from the facility.

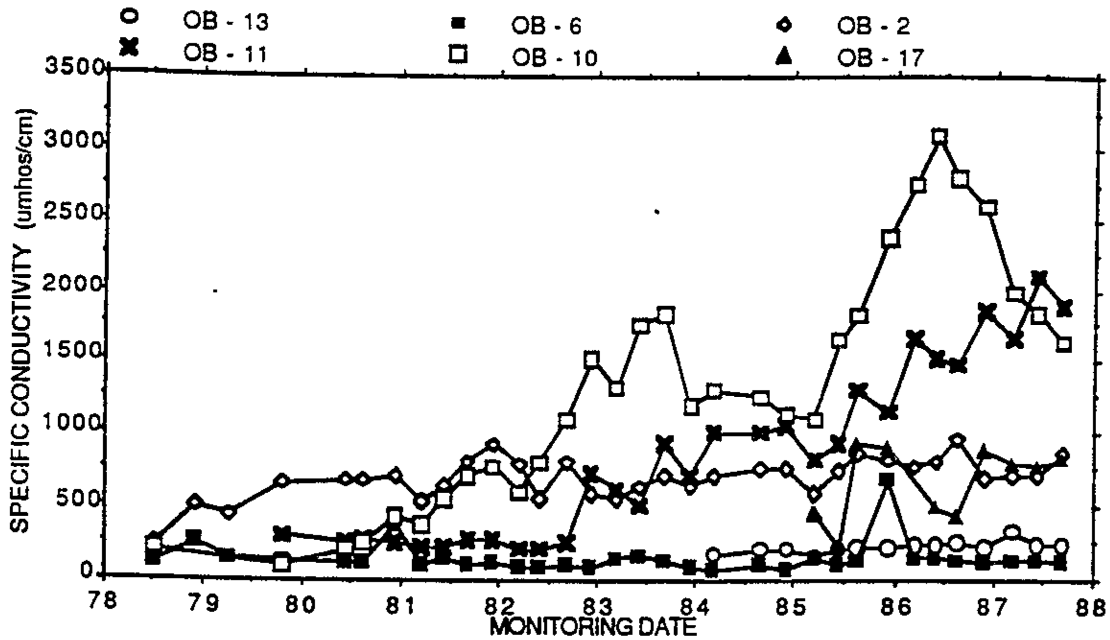
Wells OB-6 and OB-13 show background water quality conditions. The median values (midline of the boxplot) of about 120 and 220 umhos/cm indicate the natural spatial variability in specific conductance. Within well variability for specific conductance is about 200 to 300 umhos/cm about the median.

Wells OB-10 and OB-11 are clearly impacted by contamination from the landfill as evidenced by the median values of about 1250 and 800 umhos/cm compared to 120 to 220 umhos/cm for background. Note that within well variability is on the order of 500 to 2500 umhos/cm for these wells. This indicates that contaminated wells may have significantly higher variability than is found in background conditions.

Wells OB-2 and OB-17 indicate ground water quality impacts of a lesser magnitude than OB-10 and OB-11. As with the highly contaminated wells, within well variability is higher than in the background wells.

DRAFT

Time vs Specific Conductance Values



Boxplot of Specific Conductance Values

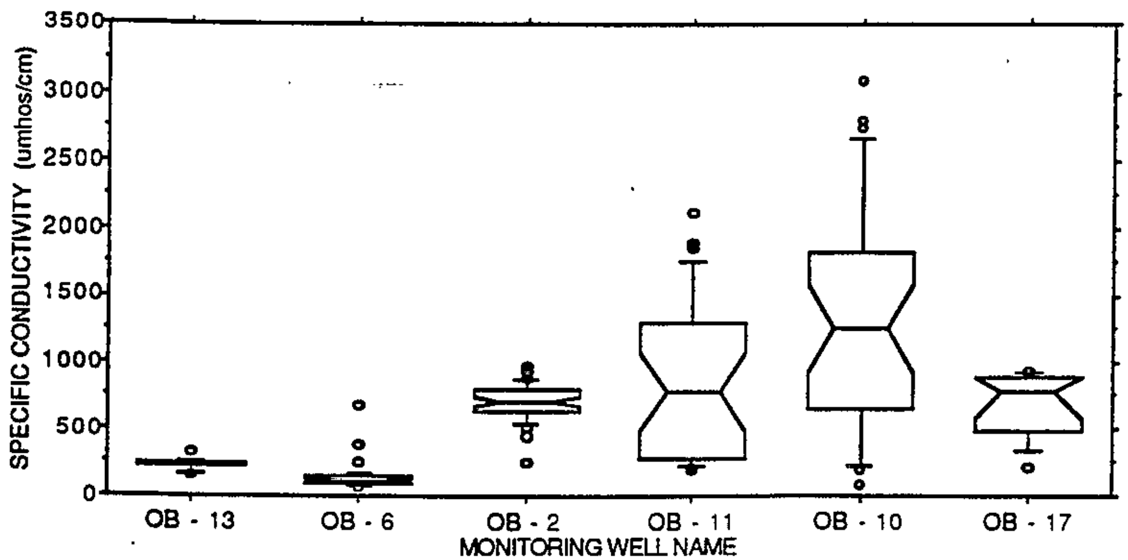


Figure 7-11. Use of Time Series Plots and Boxplots (modified after Fisher, 1989).

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APPENDIX

Minimum Standards for Construction and Maintenance of Wells

Part One--General Requirements and Part Three--Resource Protection Wells

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PART ONE—GENERAL REQUIREMENTS

WAC 173-160-010 Purpose. (1) These regulations are adopted pursuant to chapter 18.104 RCW, in order to establish minimum standards for the construction of all wells in the state of Washington. These regulations establish minimum construction standards for two classes of wells; water supply wells and resource protection wells. Water supply wells include wells used to appropriate water for beneficial purposes, cased dewatering wells, and test wells. Resource protection wells include: Monitoring wells, observation wells, piezometers, geotechnical test borings, and spill response wells.

(2) Provisions of Part One shall apply to all wells. Provisions of Part Two shall apply to water supply wells. Provisions of Part Three shall apply to resource protection wells.

(3) The following are excluded from these regulations:

(a) Excavations that are not used to locate, divert, artificially recharge, or withdraw ground water.

(b) Post holes.

(c) Landfill gas extraction wells.

(d) An excavation for the purpose of obtaining or prospecting for oil, natural gas, minerals, products of mining, quarrying, inserting media to repressure oil or natural gas bearing formations, storing petroleum, natural gas, or other products, as provided in chapter 78.52 RCW.

(e) Injection wells, such as stormwater disposal or recharge wells regulated in chapter 173-218 WAC.

(f) Cathodic protection wells.

(g) Uncased wells used for dewatering purposes in construction work, and other uncased excavations, such as uncased geotechnical test borings. However, the provisions of WAC 173-160-055, '73-160-010(4), and 173-160-420 shall apply.

(h) Infiltration galleries, tre :s, ponds, pits, and sumps.

(4) Pursuant to chapter 90.48 RCW, those excavations excluded in subsection (3)(a) through (h) of this section shall be constructed and abandoned to ensure protection of the ground water resource and to prevent the contamination of that resource. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), §

173–160–010, filed 4/6/88; Order 73–6, § 173–160–010, filed 4/30/73.]

WAC 173–160–020 General. The following minimum standards shall apply to all wells constructed in the state of Washington. It is the responsibility of the water well contractor and the property owner to take whatever measures are necessary to guard against waste and contamination of the ground water resources.

(1) It will be necessary in some cases to construct wells with additional requirements beyond the minimum standards. Additional requirements are necessary when the well is constructed in or adjacent to a source of contamination. Sources of contamination include, but are not limited to, the following: Septic systems, lagoons, landfills, hazardous waste sites, salt water intrusion areas, chemical storage areas, and pipelines.

(2) When strict compliance with these regulations is impractical, the well contractor or driller shall make application to the department for approval of comparable alternative specifications (a variance) prior to the work being done. The department shall authorize or deny a variance request within fourteen days of receipt of a written request. In an emergency, a public health emergency, or in exceptional instances, the department will allow verbal notification to the appropriate regional office, with a written request follow–up. [Statutory Authority: Chapter 18.104 RCW. 88–08–070 (Order 88–58), § 173–160–020, filed 4/6/88; Order 73–6, § 173–160–020, filed 4/30/73.]

WAC 173–160–030 Definitions. As used in this chapter:

(1) "Abandoned well" is a well which has been filled or plugged so it is rendered unproductive. A properly abandoned well will not produce water nor serve as a channel for movement of water.

(2) "Access port" is a 1/2– to 2–inch tapped hole or tube equipped with a screw cap, which provides access to the inner casing, for measurement of the depth to water surface.

(3) "Annular space" is the space between the surface or outer casing and the inner casing, or the space between the wall of the drilled hole and the casing.

(4) "Aquifer" is a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of ground water to wells or springs.

(5) "Artesian well" is a well tapping an aquifer bounded above and below by impermeable beds or beds of distinctly lower permeability than the aquifer itself. The water will rise in the well above the point of initial penetration (above the bottom of the confining or impermeable layer overlying the aquifer). This term includes both flowing and nonflowing wells.

(6) "Artificial gravel pack" is a mixture of gravel and/or sand placed in the annular space around the well screen. A gravel pack is used to reduce the movement of finer material into the well reduce the movement of finer material into the well, increase the well yield and provide lateral support to the screen in unstable formations.

(7) "Artificial recharge" is the addition of water to an aquifer by activities of man, such as irrigation or induced infiltration from streams, or injection through wells.

(8) "Bentonite" is a mixture of swelling clay minerals, predominantly sodium montmorillonite.

(9) "Capped well" is a well that is not in use and has a watertight seal or cap installed on top of the casing.

(10) "Casing" is a pipe, generally of metal or plastic, which is installed in the bore hole to maintain the opening.

(11) "Curbing" is a liner or pipe made of concrete, precast tile or steel installed in dug wells to provide a space between the well bore and the liner for sealing.

(12) "Consolidated formation" means any geologic formation in which the earth materials have become firm and coherent through natural rock forming processes. Such rocks commonly found in Washington include basalt, granite, sandstone, shale, conglomerate, and limestone. An uncased drill hole will normally remain open in these formations.

(13) "Contamination" is an impairment of natural ground water quality by biological, chemical, physical, or radiological materials which lower the water quality to a degree which creates a potential hazard to the environment, public health, or interferes with a beneficial use.

(14) "Department" means the department of ecology.

(15) "Disinfection" is the use of chlorine, or other disinfecting agent or process approved by the department, in sufficient concentration and contact time adequate to inactivate coliform or other indicator organisms.

(16) "Domestic water supply" is any water supply serving one or more single family residences.

(17) "Drawdown" is the measured difference between the static water level and the water level induced by pumping.

(18) "Drilled well" is a well in which the hole is usually excavated by mechanical means such as rotary, cable tool, or auger rigs.

(19) "Driven well" is a well constructed by joining a "drive point" to a length of pipe, then driving the assembly into the ground.

(20) "Dug well" is a well generally excavated with hand tools or by mechanical methods. The side walls may be supported by material other than standard weight steel casing.

(21) "Filter pack" means clean, well rounded, smooth, uniform, sand or gravel, which is placed in the annulus of the well between the borehole wall and the well screen to prevent formation material from entering the well.

(22) "Formation" means an assemblage of earth materials grouped together into a unit that is convenient for description or mapping.

(23) "Geotechnical test boring" means any temporary cased borehole completed primarily for the purpose of obtaining geologic, or geotechnical data about subsurface soil or rock conditions, and/or for determining ground water levels.

(24) "Grout" is a fluid mixture of cement, bentonite, and water used to seal the annular space around or between well casings, or to fill and seal abandoned wells.

(25) "Impermeable" is a descriptive term for earth materials which have a texture or structure that does not permit fluids to perceptibly move into or through its pores or interstices.

(26) "Licensee" is any person who is licensed as a well contractor pursuant to the provisions of this act and these rules.

(27) "Liner" means any casing, screen, or other device inserted into a larger casing, screen, or open hole as a means of sealing off undesirable material or maintaining the structural integrity of the well.

(28) "Landfill gas extraction well" is a well used to withdraw gas from an unsaturated zone.

(29) "Monitoring well" is a well designed to obtain a representative ground water sample and/or to measure the water level elevation over the screened interval.

(30) "Observation well" is a well designed to measure the depth to the water table. An observation well is screened across the water table and usually is installed in unconfined aquifers.

(31) "Operator" is any person employed by a well contractor or self-employed as a contractor-operator for the control and supervision of well construction or for the operation of well construction equipment.

(32) "Permeability" means the ease with which a porous material allows liquid or gaseous fluids to flow through it. For water, this is usually expressed in units of centimeters per second and termed hydraulic conductivity. Soils and synthetic liners with a permeability for water of 1×10^{7} cm/sec or less may be considered impermeable.

(33) "Piezometer well" is a well designed to measure the hydraulic potential (water level elevation) at a specific point in the subsurface. A piezometer has a short screen that is positioned entirely beneath the water table.

(34) "Pressure grouting" is a method of forcing grout into specific portions of a well for sealing purposes.

(35) "PTFE" means polytetrafluoroethylene casing materials (such as teflon) and is not an endorsement for any specific PTFE product.

(36) "Public water supply" is any water supply intended or used for human consumption or other domestic uses, including source, treatment, storage, transmission and distribution facilities where water is furnished to any community, collection or number of individuals, available to the public for human consumption or domestic use, excluding water supplies serving one single family residence.

(37) "Puddling clay" is a mixture of at least [illegible] percent bentonite and fine sand material which seals or retards the movement of water.

(38) "PVC" means polyvinyl chloride a type of th[illegible]moplastic casing.

(39) "Resource protection wells" mean monitoring wells, observation wells, piezometers and spill response wells, and cased geotechnical test borings.

(40) "Spill response well" is any well used to capture or recover any spilled or leaked fluid which has the potential to, or has contaminated the ground water.

(41) "Static water level" is the vertical distance from the surface of the ground to the water level in a well when the water level is not effected by pumping or free flow.

(42) "Temporary surface casing" is a length of casing (at least four inches larger in diameter than the permanent casing) which is temporarily installed during well construction to maintain the annular space.

(43) "Test well" is a well (either cased or uncased), constructed to determine the quantity of water available for beneficial uses identifying underlying rock formations (lithology), and to locate optimum zones to be screened or perforated.

If a test well is constructed with the intent to withdraw water for beneficial use, it must be constructed in accordance with the minimum standards for water supply wells, otherwise they shall be constructed in accordance with the minimum standards for resource protection wells.

(44) "Tremie tube" is a small diameter pipe used to place grout, filter pack material, or other well construction materials in a well.

(45) "Unconsolidated formation" means any naturally occurring, loosely cemented or poorly indurated earth material including such materials as uncompacted gravel, sand, silt and clay. Alluvium, soil, and overburden are terms frequently used to describe such formations.

(46) "Water supply well" means any well that is used to withdraw, dewater, or recharge ground water.

(47) "Well" means and includes any excavation that is drilled, cored, bored, washed, driven, dug, jetted, or otherwise constructed when the intended use of an excavation is for the location, diversion, artificial recharge, or withdrawal of ground water. Well includes water-supply well and resource protection well. Well does not mean excavations excluded in WAC 173-160-010(3).

(48) "Well contractor" means any person, firm, partnership, copartnership, corporation, association, or other entity engaged in the business of constructing wells.

(49) "Well driller" is synonymous with "operator."

(50) "Well rig" is any power driven, percussion, rotary, boring, digging, jetting or auguring machine used in the construction of a well. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-030, filed 4/6/88; Order 73-6, § 173-160-030, filed 4/30/73.]

WAC 173-160-040 Permit. As provided in RCW 90.44.050, no well shall be constructed if a withdrawal of more than five thousand gallons a day or irrigation of more than one-half acre of noncommercial lawn and garden is contemplated, unless an application to appropriate such waters has been made to the department and a permit has been granted. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-040, filed 4/6/88; Order 73-6, § 173-160-040, filed 4/30/73.]

WAC 173-160-050 Records. (1) Every well contractor, within thirty days after completion of a well, is required to submit a complete record on the construction or alteration of the well to the department. This shall apply to all water supply and resource protection wells. The well record shall be made on a form provided by the department, or a reasonable facsimile, as approved by the department.

(2) The water supply and test well record shall include the following information, where applicable, as a minimum: Location of well to at least 1/4, 1/4 section or smallest legal subdivision; intended use of well; the depth, diameter, and general specifications of each well; the depth, thickness and character of each bed, stratum or formation penetrated by each well; and the commercial specifications of all casing, also of each screen or perforated zone in the casing; the tested capacity of each well in gallons per minute; for each nonflowing well, the depth to the static water level, as measured below the land surface, and also the drawdown of the water level at the end of the well capacity test; for each flowing well, the shut-in pressure measured above the land surface, or in pounds per square inch at the land surface, and such additional factual information as reasonably may be required by the department.

(3) The well record shall be made on a form provided by the department, or a reasonable facsimile, as approved by the department. The resource protection well record shall include the following information as a minimum: Project name, if appropriate; location of well to at least 1/4, 1/4 section or smallest legal subdivision; land surface datum; well identification number; diameter; depth, and general specifications of each well; the depth thickness and character of each bed, stratum or formation penetrated by each well; and commercial specifications of all casing and screen; as-built diagram; and additional information as required by the department. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-050, filed 4/6/88; Order 73-6, § 173-160-050, filed 4/30/73.]

WAC 173-160-055 Well construction notification (start card). All well contractors shall notify the department of their intent to construct, reconstruct, or abandon a well at least seventy-two hours before starting work.

Notification shall be submitted on forms provided by the department and shall contain the well owners name, well location, proposed use, approximate start and completion dates, contractor's registration number, driller's name and license number, and drilling company's name. In an emergency, a public health emergency, or in exceptional instances, the department will allow verbal notification to the appropriate regional office, with a start card follow-up. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-055, filed 4/6/88.]

WAC 173-160-065 Design and construction. Every well shall be planned and constructed so that it is:

(1) Adapted to the geologic and ground water conditions existing at the well site to insure full utilization of every natural protection afforded thereby.

(2) Designed to facilitate such supplementary construction as may be required to provide a sufficient and safe water supply where obtainable and to conserve ground water.

(3) Capable of yielding, where obtainable, the quantity of water necessary to satisfy the requirements which the user has stated are needed and for which well water is intended to be used. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-065, filed 4/6/88.]

WAC 173-160-075 Design and construction—Sealing of casing—General. In constructing, developing, redeveloping or conditioning a well, care shall be taken to preserve the natural barriers to ground water movement between aquifers and to seal aquifers or strata penetrated during drilling operations which might impair water quality or result in cascading water. All sealing should be permanent and shall prevent movement of surface, or ground water into the annular space. Sealing shall prevent the upward movement of artesian waters within the annular space around the well casing, to prevent the contamination or wasting of ground water. Sealing shall prevent the movement of ground water either upward or downward from zones that were cased off because of poor quality. When cement grout is used in sealing, it shall be set in place seventy-two hours before additional drilling takes place, unless special additives are mixed with the grout that cause it to set in a shorter period of time. All grouting shall be performed by tremmying the mixture from the bottom of the annular space to the surface in one continuous operation. The annular space to be grouted shall be a minimum four inches larger than the permanent casing.

When casing diameter is reduced, a minimum of eight feet of casing overlap is required and the bottom of the annular space between the casings shall be sealed with a watertight packer; the remainder of the annular space must be pressure grouted with bentonite or neat cement. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-075, filed 4/6/88.]

WAC 173-160-085 Capping. All wells which are not in use, or are temporarily out of service, shall be securely capped such that no contamination can enter the well. Capping shall be affixed by solid welds or equal seal to prevent unauthorized access to the well. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-085, filed 4/6/88.]

WAC 173-160-095 Relationship to other authorities. Nothing in these regulations shall be construed to waive any legal requirements of other state agencies or local governmental entities relating to well construction nor shall it preclude the adoption of more stringent minimum well construction standards by local government. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-095, filed 4/6/88.]

WAC 173-160-105 Comparable construction standards. Nothing in these regulations shall be construed to limit the department's authority to approve comparable alternative specifications for well construction as technology in the industry develops and/or new and comparable methods of construction become known to the department. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-105, filed 4/6/88.]

WAC 173-160-115 Enforcement. In enforcement of this chapter, the department of ecology may impose such sanctions as are appropriate under authorities vested in it, including but not limited to the issuance of regulatory orders under RCW 43.27A.190, civil penalties under RCW 90.03.600 and 18.104.155, and criminal penalties under RCW 18.104.160. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-115, filed 4/6/88.]

WAC 173-160-125 Appeals. All final written decisions of the department of ecology pertaining to permits, regulatory orders, and related decisions made pursuant to this chapter shall be subject to review by the pollution control hearings board in accordance with chapter 43-.21B RCW. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-125, filed 4/6/88.]

WAC 173-160-135 Regulation review. The department of ecology shall initiate a review of the rules established in this chapter whenever new information, changing conditions, or statutory modifications make it necessary to consider revisions. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-135, filed 4/6/88.]

PART THREE—RESOURCE PROTECTION WELLS

WAC 173-160-500 Design and construction—General. (1) No resource protection well shall be used for domestic, industrial, commercial, or agricultural purposes, unless it meets the minimum construction standards for water supply wells.

(2) No resource protection well shall interconnect saturated formations or aquifers.

(3) Cuttings and development water shall be managed in a manner consistent with the intent and purposes of the Water Pollution Control Act, chapter 90.48 RCW, the Hazardous Waste Management Act, chapter 70.105 RCW, and implementing regulations (chapter 173-303 WAC).

(4) A well identification number shall be permanently attached or engraved on the inner and outer well casings. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-500, filed 4/6/88.]

WAC 173-160-510 Design and construction—Surface protective measures. (1) Every resource protection well shall be capped and protected using one of the following methods:

(a) If the well is cased with metal and completed above the ground surface, a lockable cap shall be attached to the top of the casing.

(b) If the well is not cased with metal and completed above the ground surface, a metal protective casing shall be installed around the well. The protective casing shall extend at least six inches above the top of the well casing and at least two feet into the ground. A lockable cap shall be attached to the top of the protective casing.

(c) If the well is completed below ground surface, a lockable "water-meter cover," or equivalent, shall be installed around the well. A protective cover, level with the ground surface, shall be installed with a waterproof seal to prevent the inflow of surface water. Drains shall be provided, when feasible, to keep water out of the well and below the well cap. The cover must be designed to withstand the maximum expected loadings.

(2) The well(s), completed above ground, shall be protected from damage by one of the following methods:

(a) Three metal posts at least three inches in diameter, and set in concrete, shall be installed in a triangular array around the casing and at least two feet from it. Each post shall extend at least three feet above and below the ground surface.

(b) A reinforced concrete pad may be installed to prevent freeze/thaw cracking of the surface seal. When a concrete pad is used, the well seal shall be part of the concrete pad.

(c) A protective cover shall be installed when the well is completed below the ground surface. The cover must be designed to withstand the maximum expected loadings.

(3) The protective measures may be waived, if the well is inspected at least weekly and is located in a secure area that is not susceptible to vandalism or to damage.

(4) If the well is to be protected by other surface protection methods, the owner shall obtain prior written approval from the department.

(5) If the well is damaged, the well protection measures and casing shall be restored as prescribed by this chapter. If the well is damaged beyond repair, it shall be properly plugged and abandoned in accordance with WAC 173-160-560. [Statutory Authority: Chapter 18-.104 RCW. 88-08-070 (Order 88-58), § 173-160-510, filed 4/6/88.]

WAC 173-160-520 Design and construction—Casing. The casing shall be nonreactive with the subsurface environment. The casing shall not effect or interfere with the chemical, physical, radiological, or biological constituents of interest. All rescurce protection well casing shall conform to ASTM Standards, or at least 304 or 316 stainless steel, PTFE, or Schedule 40 PVC casing. Glued casing joints shall not be used in areas of known or potential contamination. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-520, filed 4/6/88.]

WAC 173-160-530 Design and construction—Cleaning. (1) When drilling in known or potential areas of contamination, the drill rig derrick and all drilling equipment shall be steam cleaned before and after well construction.

(2) The casing and screen(s) shall be steam cleaned and rinsed before installation, and stored off the ground on secure clean racks.

(3) The filter pack shall be washed with clean water before installation and shall not interfere with the chemical, physical, radiological, or biological constituents of interest. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-530, filed 4/6/88.]

WAC 173-160-540 Design and construction—Well screen, filter pack, and development. (See Figure 7 at the end of this section.) (1) Wells installed for water quality sampling shall include the following:

(a) Commercially fabricated screen. The well screen shall be constructed of material that is nonreactive to subsurface conditions.

(b) Filter pack. A filter pack is preferred, but not required in coarse or granular formations. When used, it shall be installed from the bottom of the screen to at least three feet above the top of the screen.

(c) Well development. The well shall be developed to assure continuity between the well, well screen, and formation materials.

SEE ILLUSTRATION
(WAC 173-160-540, Figure 7)

Figure 7. GENERAL RESOURCE PROTECTION WELL—CROSS SECTION
[Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-540, filed 4/6/88.]

WAC 173-160-550 Design and construction—Well seals. (1) A layer of bentonite at least two feet thick shall be placed on top of the filter pack. Figure 7 illustrates the well construction.

(2) The annular space shall be grouted with bentonite; or a bentonite -cement sealant, which has a weight in the range of eleven to thirteen pounds per gallon as verified on site, with a mud balance. Monitoring wells designed to retain the outer casing shall be sealed into the first impermeable layer. The sealant shall be installed with a tremie tube from the bottom up. Use only potable water to hydrate the mixture.

(3) Other methods may be used to seal the annular space, if they provide equivalent protection, and a variance has been issued by the department. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-550, filed 4/6/88.]

WAC 173-160-560 Abandonment of resource protection wells. (1) If it can be verified that a resource protection well was constructed in accordance with these regulations, it shall be abandoned by filling the casing from the bottom to the surface with grout or bentonite. If the construction cannot be verified, the well shall be abandoned in accordance with WAC 173-160-415(2).

(2) The abandonment procedure shall be recorded on a form provided by the department and shall include, as a minimum, the following information: Project name, if appropriate; date; location of well by 1/4, 1/4, section or smallest legal subdivision; well identification number; use of well; method of setting the plug; type and amount of sealant used; and such additional information as required by the department.

(3) The well abandonment must be recorded and reported to the department within thirty days of abandonment. [Statutory Authority: Chapter 18.104 RCW. 88-08-070 (Order 88-58), § 173-160-560, filed 4/6/88.]

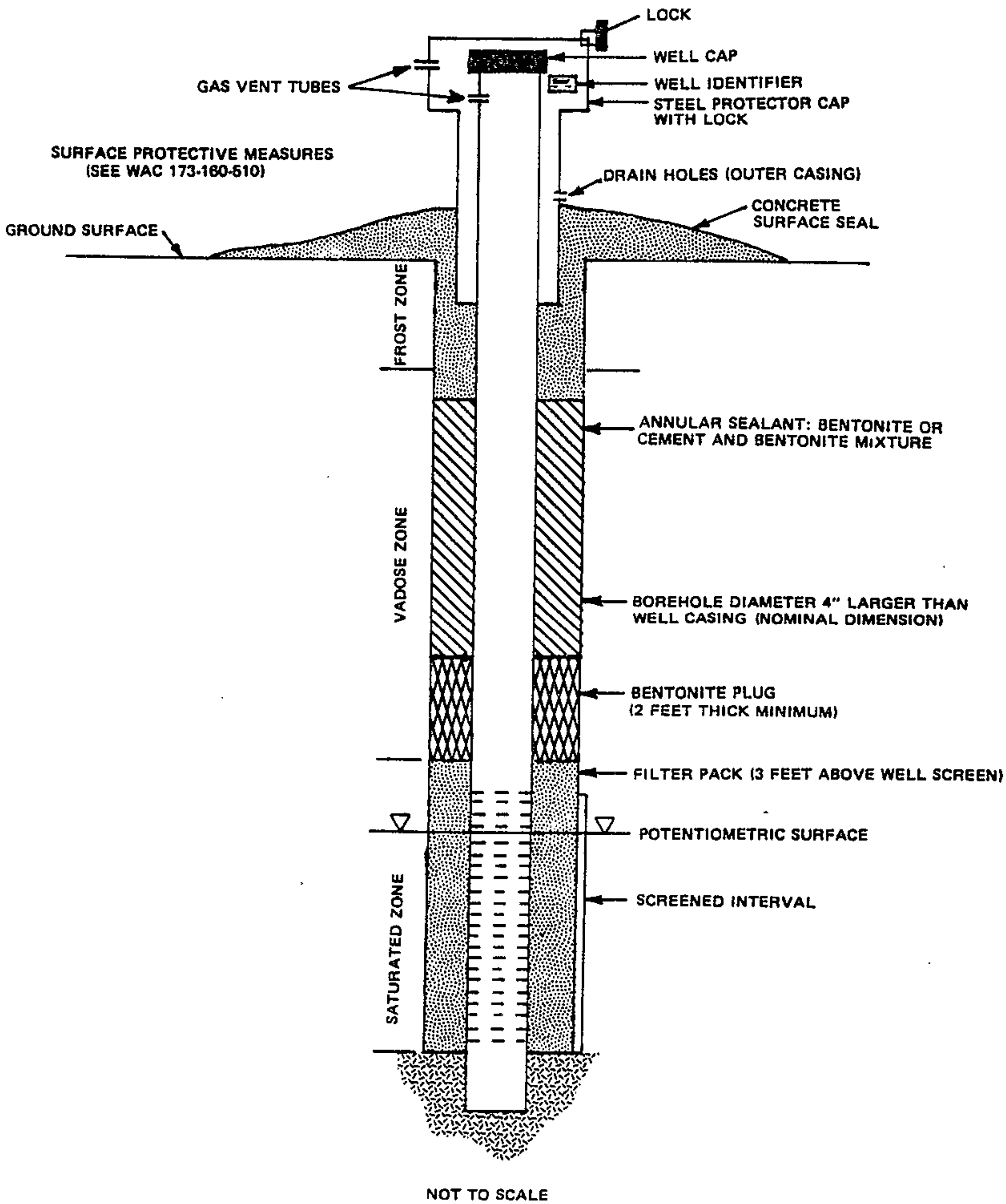

Figure 7. GENERAL RESOURCE PROTECTION WELL—CROSS SECTION.

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